SIR JOHN RENNIE

ON

CIVIL ENGINEERING.

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Joseph Hume
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INSTITUTION OF CIVIL ENGINEERS.

ADDRESS

OF

SIR JOHN RENNIE,

PRESIDENT,

TO THE

ANNUAL GENERAL MEETING.

JANUARY 20, 1846.

LONDON.

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SINCE I last had the honour of addressing you from this Chair, another year has elapsed. The Institution has continued to prosper, and our profession, from which it emanated, and by which it is supported, continues to extend its sphere of usefulness ; and its importance, which becomes daily more and more acknowledged, renders our future prospects equally cheering. Before I attempt to point out the course which it behoves us to pursue as regards ulterior proceedings, let us pause and take a retrospective glance at the changes which have been effected in Great Britain since the days of that great man Smeaton, to whose genius and exertions Civil Engineering may be said to owe its establishment as a profession in this country. Previous to that period (1724), Great Britain may be said, comparatively speaking, to have been lamentably deficient in public works. There were no canals, railways, nor artificial harbours, or machinery, which at the present day would be thought worthy of the name ; and the public roads were little better than mere tracks across the country. Communication between towns was difficult ; and the few wheeled-carriages in use were of a rude and inefficient description. The inland commerce of the country was chiefly carried on by transport on the backs of "*pack-horses* ;" and the old-

fashioned term *load*, so commonly in use as a measure or weight, is a remnant of that custom—meaning a horse-load. The luxuries, and even necessaries of life, were, consequently, extremely dear and difficult of attainment. Inland navigation, which was carried on in the rivers as nature had left them, was both tedious and uncertain; and this navigation, imperfect as it was, could only be adopted at times when there was sufficient water, arising from floods, or other causes; occasionally (but of this the instances were very rare) rude temporary stanches, or flash-weirs, were used to pen up the running water in shallow places; these weirs, or stanches, were then suddenly withdrawn, and thus the increased depth of water and the current enabled the boats to float over them; these were followed by rough unwalled locks; then by short side-cuts to avoid the difficult places of the rivers; in these side-cuts the pound-lock was introduced, with side-weirs to enable the floods to escape, and to supply mills with water, thus answering the double purposes of navigation and supplying power for machinery.

The above may be taken as the extent of improvement to which inland navigation had arrived in Great Britain up to the middle of the last century. The navigation of the ocean, depending upon the inconstant agency of the winds and tides, required months, nay, years, for communicating between distant quarters of the globe. The reckoning of a ship's course, during a long voyage, was most uncertain; neither chronometers, nor lunar observations, nor accurate instruments for making such observations, were known.

The Steam-Engine (to the honour of inventing which so many individuals lay claim), which had, in 1698, been so far improved, and was, for the first time, constructed by Savery so as to be employed as an efficient agent for raising water, was brought into active operation in 1712, by means of a steam cylinder, into which cold water was injected for causing a vacuum, so as to enable a moveable piston to be impelled by the pressure of the atmosphere, and thus, by the intervention of a lever, to work pumps for raising water; this was further improved by Potter and Beighton (1713–18), so as to become self-acting; and thus Newcomen's engine, by degrees, became generally adopted for pumping water from collieries, and from a few rich mines, and for supplying the metropolis with water; but the consumption and expense of fuel were so considerable, that, even great as were the advantages derived from its employment, still its application was very limited. After Beighton, followed Leupold, Hulls, Belidor, Payne, Blake, Fitzgerald, Emerson, and others, who made various suggestions, without, however, adding anything material to the engine as improved by New-

comen, Potter, and Beighton. The relation between the quantity of fuel consumed and the effect produced by an engine, had never been determined; and knowledge was wanting for the investigation of the important subject, until Black and Cavendish, in 1760–62, had made their experiments and discoveries on the combination of heat with bodies in their solid, liquid, and gaseous states. Notwithstanding the great advantages resulting from the employment of Newcomen's engine, still, for the reasons above mentioned, its application was very limited; wind and water were alone used as powers for driving machinery and working mills, which were rare, and only adapted for performing rude mechanical operations, such as grinding corn, fulling cloth, pumping water, blowing furnaces, hammering and rolling iron, and such other purposes as the feeble powers of human labour were unable to accomplish; and with the exception of the silk mills introduced from Italy by Sir Thomas Lombe at Derby in 1720, and which were worked by water, there was nothing in the nature of manufacturing machinery.

Smeaton, born in 1724, at an early age applied his ingenious and vigorous mind to the cultivation of philosophical knowledge, and thought for the benefit of mankind. He commenced his career as a mathematical-instrument maker in 1750; after obtaining some celebrity in the scientific world by his air-pump in 1752, he took up the subject of wind and water-mills, which had, up to that period, been much neglected, and soon made such improvements in them as greatly increased their powers and efficiency; he constructed several of both kinds, according to his improved principles, with great success, which were considered as models, and soon afterwards universally followed. In 1753 he was elected Fellow of the Royal Society; in 1759 he communicated his celebrated paper (being the results of his experiments in 1752 and 1753) on the natural powers of wind and water to turn mills and other machinery depending on circular motion, for which he obtained their gold medal. These improvements of Smeaton were of manifold importance, and produced, directly and indirectly, the most beneficial results, as they enabled a greater quantity of work to be performed both by wind and water, particularly during temperate and dry seasons; hence, better roads became necessary, to carry away the increased produce of the mills; and when they were worked by water on rivers, the mill-owner became interested in the improvement of the navigation, and, by economising the water on Smeaton's plan, obtained one-third greater result with the same quantity, thus benefiting himself as well as the navigation. Windmills have been rendered still more perfect than Smeaton left them, by making them

self-regulating as to the extent of the surface of their sails presented to the action of the wind, according to the form and mode invented by Meikle in 1772; by Bywater, in 1804, with an improved mode of clothing the sails; and still further by our valuable member, Cubitt, in 1807, who brought the system to perfection. Smeaton was amongst the first to point out the laws which govern the formation and maintenance of harbours; and, after undertaking a voyage of observation through Holland, he introduced great improvements in the draining of marsh lands (as at Holderness and the North Level), a subject which had up to that period been very imperfectly understood; and, by the design and construction of the celebrated Eddystone lighthouse in 1755-59, Smeaton introduced a new æra in masonry, which forms a brilliant epoch in his valuable life, spent in the service of mankind, but more particularly for the benefit of his country.

In 1765 Smeaton directed his attention to Newcomen's engine, and constructed a small engine, at his own house at Austhorpe, in order to conduct his experiments and obtain more accurate results in practice. By the judicious improvements which he introduced in the proportions and structure, he diminished materially the consumption of fuel, then an object of paramount importance, and soon after constructed engines on Newcomen's principle, which far exceeded anything of the kind hitherto produced: amongst these may be mentioned the engines at Long Benton, near Newcastle, and at Chasewater, in Cornwall: he thus rendered the system of Newcomen as perfect as it could be made. From the improvements of Smeaton on wind and water-mills, we may date the foundation of the modern system of manufacturing, and from those in Newcomen's engine the modern system of mining.

In 1736 Watt was born, and from his early years manifested symptoms of that genius and sagacity which, at a later period, enabled him to work out, with wonderful success, those grand discoveries which have immortalized his name. He began his career as a mathematical-instrument maker, and subsequently became an Engineer. He proposed a plan for improving the river Clyde, and suggested the idea of the Caledonian Canal, but afterwards devoted himself almost exclusively to the improvement of the steam-engine. His improvements, or rather inventions, may be stated, generally, as follows:—the separate condensing vessel, with an air-pump for exhausting the steam cylinder, instead of injecting cold water into it, for impelling the piston on Newcomen's plan, by atmospheric pressure; in conjunction with Boulton, he brought these improvements into operation about the year 1773, and produced a still greater diminution in the consumption of fuel than Smeaton had done; thus rendering the

application of the steam-engine for pumping water much more general. In 1781 he invented the means of producing rotatory motion by the steam-engine, first by the crank, and afterwards by the sun and planet wheel, thus rendering it applicable for the purpose of driving all kinds of machinery, which was a grand step towards the improvement of manufactures. In 1777–82 he invented the application of steam, with expansive action and with double action, alternately above and below the piston. In 1784 he invented the parallel motion, or working gear and valves, the governor, and other important details. All these improvements or inventions were carried into effect in an engine made by Boulton and Watt, in 1784, for one of the London breweries, and in 1785 in others for the Albion mills, which were the first steam-mills, now become so general; thus steam power was rendered available for working machinery of every kind, by following the best examples of this most wonderful and useful of all machines, which has so deservedly immortalized the name of Watt. The account of the extraordinary labours and inventions of Watt and his successors is well given by our valuable member, Farey, in his excellent work on the steam-engine, to which I would refer you, and also to the treatises by Tredgold, Arago, Scott Russell, and others.

About this period (1716), Brindley, who may be justly called the father of inland canal navigation in England, was born. He commenced his career as a millwright, and was withdrawn from that occupation by the Duke of Bridgewater in 1758, for the purpose of executing his great canal. Pound locks had been introduced long before on river navigations, and on the Exeter and Topsham Canal, which was commenced in 1581, and terminated about 1695; they were also used on the Sankey Canal in 1755, for the purpose of rendering Sankey Brook navigable; which was effected by making an almost entirely new channel. Brindley subsequently executed, with great success, the Trent and Mersey, or Grand Trunk, the Leeds and Liverpool, the Birmingham, the Forth and Clyde canals, in conjunction with Smeaton and several others, with all the necessary works belonging to them, which will ever remain as lasting monuments of his skill and genius in this valuable department of Civil Engineering. At an early period of the reign of George III., the importance of canal navigation became universally acknowledged as one of the greatest means, then known, of facilitating the transport and reducing the cost of the necessaries and luxuries of life, and thus contributing to the wealth and prosperity of every part of the kingdom; those prejudices and obstacles by which, at the outset, every great improvement is surrounded, gradually began to give way, canals became popular, and super-

seded river navigation so much as to call forth the celebrated answer of Brindley to the question, "What is the use of rivers?"—"To supply canals." Engineers who had displayed such abilities in planning and executing works of the nature above described, began to acquire that importance as a profession which was soon after destined to work such a beneficial change, nay, almost a revolution, in society, and accelerate so greatly the civilization of mankind.

Smeaton and Brindley were accompanied and followed by a number of able men in rapid succession; amongst whom were Jessop, Whitworth, Mylne, Yeoman, Henshall, Golborne, Huddart, Rennie, Ralph Walker, Chapman, Telford, and others, all stimulated to exertion by the magnificent career before them, each contributing, more or less according to their several opportunities, great skill and invention of their own, in addition to that acquired from their predecessors. Favoured by the command of great funds (which were rapidly forthcoming as the success of the works already executed became manifest), better workmen and materials, new and improved machinery, steam power, and greater influence over the public mind, their operations were conducted upon a scale of magnitude, utility, and importance, which gave a new character to the age in which they flourished, and advanced the prosperity of the empire.

To attempt to enumerate all the various public works which then crowded each other in rapid succession, constituting the character of the profession, and entitling it to public confidence, would be both difficult and tedious; they are well-known and duly appreciated, and it will suffice to point out some of the most important. The Forth and Clyde Canal by Smeaton (1768), length 24 miles, depth 8 feet, locks 19 feet by 75 feet, top-width of canal 66 feet; the Ellesmere by Jessop and Telford, with its magnificent aqueduct across the Dee near Llangollen, consisting of 19 arches 40 feet span, the centre being 126 feet above the Dee, with a total length of 1020 feet, and a width of 12 feet, the piers of stone, and the arches and aqueduct of cast iron; the Caledonian Canal by Jessop and Telford, 22 miles long, depth 16 feet, locks 40 feet wide by 172 feet long, 8 feet rise, top-width of canal 110 feet; locks intended for a depth of 20 feet; commenced in 1803, opened October, 1820; the first and last of which, together with the Gloucester and Berkley Canal, may be cited as the first upon which sea-borne vessels could navigate, and thus extend the benefits of ship navigation into the interior of the country, without the delay and expense of transhipment of cargoes until arriving at the warehouses where they are to be distributed; the Grand Junction (Jessop and Whitworth), Lancaster, and Kennet and Avon (Rennie). On the Lancaster navigation the canal is carried across

the Lune by a stone viaduct of 5 semicircular arches, 75 feet span each; the total length of viaduct is 600 feet, and height 55 feet above the river. The Aire and Calder, the Union, the Shrewsbury, New Birmingham and Liverpool, Carlisle, the Grand and Royal Canals, Ireland, amongst many others may be quoted as examples of artificial canals for vessels, so as to enable them to continue their navigation inland from large rivers and estuaries. The total length of canal navigation now in operation in England, Scotland, and Ireland, amounts to about 3000 miles. The most advantageous speed for boats on a canal is about 2½ miles per hour, at which rate an average horse is capable of drawing about 22 tons without injuring his physical powers; when this is much exceeded, the ratio of resistance approaches the cube of the velocity. The weight must be diminished in proportion, and the horse exerts his powers to great disadvantage. Large canals, where practicable, on account of the trade and other circumstances, are preferable to small ones, as they are worked more economically. Various contrivances have been made to obviate the necessity of locks in overcoming extensive lifts or declivities; amongst these may be mentioned the inclined planes on the Duke of Bridgewater's and the Tamar and Shrewsbury canals; double locks, side ponds, hydraulic lifts, by Woodhouse, Salmon, Congreve, Underhill, Green, and others; but extensive reservoirs and feeders are indispensable in most districts where there is great traffic, and steam-engines have been extensively used to pump back the water to be used over again in case of deficiency. The improvement of the River Clyde, begun by Watt and Golborne, received fresh stimulus under Rennie and Telford, from the application of steam power to the dredging machine by Grimshaw, in 1796, and Bentham in 1802; thus forming a new æra in the means of improving river navigation and harbours, since which time this important department of engineering has been carried to an extent which could not otherwise have been attempted. Steam-dredging machinery is now generally adopted with success, more particularly in rivers where their beds and channels can be excavated to a certain degree of uniformity, and where the inclination of the tidal and freshwater currents can be reduced to such an extent, by the removal of obstructions, as will enable them to keep their channels open. As successful examples of this, I need only adduce the Lagan, the Boyne, the Newry, the Liffey, and the Shannon, in Ireland; the Clyde, the Leith, the Don, in Scotland; the Tyne, the Wear, the Tees, the Thames, the Dee, the Ribble, the Severn, and others, in England; and as to harbours, most, if not all of them can be maintained by steam-dredging, in addition to other means, to a greater depth than could be obtained without such an important aid.

BRIDGES.

Westminster Bridge, by Labelye in 1740–47, may be considered the first example of extensive structures of this kind. It consists of 13 semicircular arches (the centre of which is 75 feet span), 164 feet long; it was originally intended for a wooden bridge, and was partly commenced on this principle; it was a great work at the time, but as might have been expected, contained defects, particularly in the foundations, which at that time were but imperfectly understood, and have suffered much by the scour of the current: it will probably be rebuilt in a short time. Caissons, or water-tight chests, were first introduced there for the purpose of founding the piers below the level of low-water. Previous to this, the principal existing bridges consisted of a number of small Gothic or of circular arches, with rough piers of masonry built either upon a foundation of loose rubble stones thrown promiscuously into the river until sufficiently high and solid, or upon timber platforms resting upon piles surrounded by large bulwarks of timber, filled with loose stones, called starlings, which materially contracted the water-way where they were placed, and by causing increased rapidity in the current, created great obstacles to the navigation, as well as to the drainage of the adjacent country. Of this, the well-known examples of Old London Bridge, those at Newcastle-upon-Tyne, Rochester and Belfast, may be mentioned. All these, with the exception of Rochester bridge, are now removed, and are replaced with others constructed upon the modern improved principles. Westminster Bridge was followed by that of Blackfriars by Mylne (1760–71), consisting of 9 semi-elliptical arches, the largest of which is 100 feet span and 41 feet 6 inches rise; the total length of the bridge is 995 feet, and 45 feet wide; here the elliptical arch was introduced about the first time in this country. Smeaton's bridges of Coldstream across the Tweed, in 1763, composed of 5 circular arches, the largest of which is 61 feet span; that over the Tay at Perth, in 1766, of 9 circular arches, the largest of which is 75 feet span; at Hexham, over the Tyne, in 1767, of 9 circular arches, the largest of which is 52 feet span, and others, for that period, were works of considerable magnitude. These were followed by numerous smaller works all over the kingdom, more remarkable for convenience and utility than for any peculiarity in their construction worthy of notice, until 1809–17, when Waterloo Bridge, across the Thames, consisting of nine equal semi-elliptical arches, 120 feet span each, and 35 feet rise, was built of granite in a style of solidity and magnificence hitherto unknown; there the elliptical

arch, with inverted arches between them to counteract the lateral pressure, was carried to a greater extent than in former bridges, and isolated coffer-dams upon a great scale in a tidal river, with steam-engines for pumping out the water, were, it is believed, for the first time employed in this country: the level line of roadway, which adds so much to the beauty as well as the convenience of the structure, was there adopted. The Bridge across the Severn at Gloucester in 1828, by Telford, is worthy of remark, as being the first with one arch, of 150 feet span, like those of the bridge across the Seine at Neuilly, near Paris, by Perronet, where the interior of the arch is elliptical and the exterior circular.

New London Bridge (1825–31), consisting of five semi-elliptical arches, viz. two of 130 feet, two of 140 feet, and the centre 152 feet 6 inches span, and 37 feet 6 inches rise, is perhaps the largest elliptical arch ever attempted; the roadway is 52 feet wide. This bridge deserves remark on account of the difficult situation in which it was built, being immediately above the Old Bridge, in a depth of from 25 feet to 30 feet at low water, on a soft alluvial bottom, covered with large loose stones, scoured away by the force of the current from the foundation of the Old Bridge, the whole of which had to be removed by dredging, before the coffer-dams for the piers and abutments could be commenced; otherwise it would have been extremely difficult, if not impracticable, to have made them water-tight; the difficulty was further increased by the Old Bridge being left standing, to accommodate the traffic, whilst the New Bridge was building, and the restricted water-way of the Old Bridge occasioned such an increased velocity of the current, as materially to retard the operations of the New Bridge, and at times the tide threatened to carry away all before it. The great magnitude and extreme flatness of the arches demanded unusual care in the selection of the materials, which were of the finest blue and white granite from Scotland and Devonshire; great accuracy in the workmanship was also indispensable. The piers and abutments stand upon platforms of timber resting upon piles about 20 feet long. The masonry is from 8 feet to 10 feet below the bed of the river.

I will conclude this division of the subject with the celebrated bridge across the Dee at Chester. It consists of a single arch, the segment of a circle 200 feet span, with a versed sine or rise of 42 feet, which is the largest stone arch upon record; the arch stones at the crown are 4 feet 6 inches deep, and 7 feet at the springing, and the abutments on both sides of the river are founded on the new red sandstone. The centre for building the arch was remarkable for its simplicity, strength and rigidity, by which means the greatest effect was produced by the smallest quantity of timber, and any change of form, so prejudicial

in centres, was prevented. This fine structure is due (it is believed) to the combined talents and energies of the late Mr. Harrison, the architect, of Chester, who made the original design; to Mr. George Rennie, who equilibrated the arch, and gave the proper dimensions of the voussoirs and form and dimensions of the abutments, the mode of constructing them, and designed the centre, the original model of which is now in our gallery; and to Mr. Jesse Hartley and Mr. Trubshaw, who worked out the details and carried the whole into effect. Pont-y-tu Prydd, over the Tafe, by Edwards, 1750, is also worthy of remark, from its simplicity and boldness: it consists of a single arch 140 feet span (the segment of a circle 175 feet diameter), with a versed sine or rise of 35 feet.

A proper theory of the equilibrium of the arch, which shall satisfy all the conditions of the question when applied to practice, may be said to be still wanting, though much valuable information may be derived from the scientific works of Hutton, Attwood, Moseley, Gwilt, and others, on the subject.

Oblique or skew bridges have but recently obtained extensive use. Chapman built some in Ireland many years ago, and wrote an account of his mode of constructing them. On railways they were, it is believed, introduced by Stephenson, and are now generally employed. Buck's excellent treatise on the principles and practice of their construction greatly facilitated their execution.

IRON BRIDGES.

The introduction of cast iron for the construction of bridges commenced about the year 1779, when that over the Severn, near Coalbrook Dale, by Darby, was the first; it consists of a circular arch 100 feet span, and a versed sine of 45 feet, approaching nearly to a semicircle; the height of the springing is 10 feet above low water, and the total height to the underside of the soffit is 55 feet; the banks of the Severn being high, this form accords well with them. It is formed by five ribs of cast iron, with perpendicular spandril pieces, resting upon them to support the roadway. This for the first attempt is well-adapted to the situation, and has answered the purpose. This was followed by the bridge over the Wear, at Sunderland: the design for this was said originally to have been made by Thomas Paine, the well-known political writer, and was cast at Rotherham, being intended for erection in America; but the materials were subsequently employed in constructing Sunderland Bridge, under the direction of Wilson in 1796, the idea having been suggested by Rowland Burdon. The curve of the arch is that of a segment of a circle, the length of the chord or span

is 200 feet, and the versed sine or rise 30 feet: the total height from low water to the underside of the soffit of the arch is nearly 100 feet. It consists of six ribs, each composed of 105 cast-iron radiating pieces, connected at the top and bottom by the circular pieces which form the curve of the arch; these ribs are united in their transverse direction by tie-pieces; the spandrils are filled in with cast-iron circles, touching each other at their circumferences, and supporting the roadway, which consists of a strong frame of timber, planked over and covered with a cement of tar and chalk, upon which a layer of marl, limestone and gravel is placed. The centre deserves notice on account of the difficulty and confined nature of the situation, which rendered it necessary to preserve a constant passage for ships with their standing rigging; this was effected by a perpendicular framing resting upon piles in the bed of the river, with a sufficient opening on each side for the vessels. Upon the top of this perpendicular framing, the transverse framing or centre for supporting the arch was fixed, and answered its purpose well. Some time after the removal of the centre, the arch was observed to swerve bodily in a horizontal direction to the eastward, forming a curve having a versed sine of about 12 or 18 inches; if this had continued to increase, it would no doubt have soon occasioned the downfall of the structure; it was, however, very skilfully remedied by the introduction of transverse and diagonal tie bars and braces, assisted by wedges and screws; so that ultimately the whole was brought back and secured in its original form and position, where it has since remained in a substantial state without alteration. The width of the bridge is 30 feet; the abutments are of stone, founded on rock; they are 24 feet thick, and from 42 feet to 37 feet wide. This bridge, for boldness of the design and construction, as well as for its elegance and lightness, must be considered a work of peculiar merit; particularly if the period in which it was constructed be remembered.

About the same time the bridge at Buildwas, across the Severn, by Telford, was erected. It consists of a single arch, segment of a circle, whose chord or span is 130 feet, and versed sine or rise 27 feet, the depth of the iron frame forming the arch being 3 feet 10 inches; it consists of 3 ribs, 18 feet wide from out to out, connected together in their transverse direction by tie-bars. The spandrils for supporting the roadway consist of vertical pieces, resting upon the segments forming the arch; the abutments are of stone. There is a novelty in the construction of this bridge worthy of remark. The two outer ribs consist of two segments of circles each struck from different centres, the crown of one terminating immediately below the roadway, the other at the top of the parapet, so that the platform forming the roadway is both suspended and insistent; the

object of this being, it is presumed, to increase the depth of the truss supporting the roadway, and thus to add to the strength of the bridge: but it was unnecessary, and does not appear to have been adopted in any of Telford's subsequent designs, which are numerous. Amongst them may be mentioned that of Bonar, Tewkesbury bridge over the Severn, also that over the Dee, near Corwen, &c. Bristol bridge over the Avon, by Jessop, is a neat simple structure. Boston bridge, by Rennie, over the Witham, of 100 feet span, with a versed sine of 4 feet, is remarkable for its boldness and lightness. The principle of construction resembles that of Sunderland, but is an improvement upon it, in having a better system of transverse and diagonal braces, and the spandrils consisting of vertical instead of circular pieces. All these have, however, been far exceeded by the Southwark bridge over the Thames, by Rennie. This consists of three arches, all segments of the same circle; the centre arch is 240 feet span, with a versed sine or rise of 24 feet, and the two side arches are 210 feet span each, with a versed sine or rise of 18 feet 10 inches each. The arches are formed by eight solid ribs in each, and each rib consisting of fifteen pieces, 6 feet deep at the crown of the arch, increasing to 8 feet deep at the springing, $2\frac{1}{2}$ inches thick in the middle, and $4\frac{1}{4}$ at the top and bottom: these ribs are connected together in their transverse direction by cast-iron tie braces of the same depth as the ribs, but open in the centre, and in the diagonal direction by another series of ribs; the whole of the segmental pieces forming the arch, as well as the transverse and diagonal tie braces, are kept in their places by dovetailed sockets and long cast-iron wedges, so that bolts for holding the several pieces together are unnecessary, although they were used during the construction of the bridge to keep the pieces in their places until the wedges had been driven. Thus the ribs formed, as it were, a series of hollow masses or voussoirs similar to those of stone, a principle which it is believed is new in the construction of cast-iron bridges; but it has succeeded so well that it is worthy of adoption elsewhere. The spandrils are composed of cast-iron diagonal pieces, connected together in a similar manner, and the roadway is formed by solid plates of cast-iron resting upon the spandrils, and joined together by iron cement. The piers and abutments are of stone, founded upon timber platforms, resting upon bearing piles, and surrounded by sheathing piles, driven sufficiently deep below the bed of the river. The masonry is tied throughout by vertical and horizontal bond stones, so that the whole acts as one mass in the best position to resist the horizontal thrust. The ribs forming the arches were commenced in the centre, and were continued regularly on each side towards the piers and abutments, upon which a cast-iron bed and connecting plate were laid, nicely let into the masonry to receive the

ribs forming the arches; when the last segment of each rib was fixed in its place, three cast-iron wedges, each 9 feet long and 9 inches wide, were placed behind each rib, and nicely adjusted and fitted to them; these having a very slight taper, were driven simultaneously by heavy hammers, and thus the arches were nearly lifted from the centres, so that the wooden wedges upon which the segment pieces rested were easily removed by a few blows of a hammer; the arches were thus relieved from the centres in a very simple and efficient manner. The whole of the iron-work had been so well put together by Messrs. Walker, of Rotherham, the founders, and the masonry by the contractors, Messrs. Jolliffe and Banks, that when the work was finished scarcely any sinking was discernible in the arches. During the progress of the work, some experiments were made, in order to ascertain the extent of the expansion and contraction between the extreme range of winter and summer temperature; and upon taking the average of numerous trials by different gauges, it was found that the crown of the arch rose in the summer about an inch to an inch and a half. The work was commenced in 1813, and the bridge was opened in 1819.

Whilst upon the subject of cast-iron bridges, we must not omit the Swivel or Turning Bridge. The invention, if it may be so termed, is, it is believed, due to England; and one was first made of iron about the year 1810. They are now almost universally adopted over locks, to the extent of 60 feet span, in preference to the old lifting bridge. Since the introduction of the railway system, cast-iron bridges have become very general, and have been particularly serviceable, being formed of girders, where the height was too limited to admit of the arch principle being adopted. Experience of the value of wrought iron in roofs, and for other building purposes, has induced R. Stephenson to propose that material for constructing the bridge to carry the Chester and Holyhead Railway across the Menai Straits. His design consists of a close wrought iron tunnel or tube, 14 feet wide, 30 feet deep, and 1500 feet long, supported in the middle by a stone pier built upon a rock in the middle of the Straits, with two other piers at the low-water mark on either side, leaving four openings, two of them 460 feet, and two of 230 feet each, and 100 feet above high water, so as to admit of masted vessels sailing under it. Cubitt has also proposed to adopt wrought iron on a great scale, for constructing landing platforms at Liverpool, where the difficulty of building docks or quays, which large steam-vessels can approach at all times of tide, renders works of this kind necessary to accommodate the immense traffic frequenting Liverpool. The landing platform designed by Cubitt, and now in course of construction, consists of a wooden frame, 500 feet long by 80 feet wide, floated upon a number of wrought iron pontons, each 80 feet long, 10 feet wide,

and 6 feet deep; it is connected with the shore by two bridges, each formed of two hollow wrought iron beams, 150 feet long, carrying the platform of the bridge: the attachment with the shore and the stage is so made as to admit of motion, both vertically and horizontally, to accommodate itself to the rising, falling, ebbing and flowing of the tide, which there rises about 30 feet.

SUSPENSION BRIDGES.

The invention of chain or suspension bridges is said to have been imported from China and India. The first of the kind in England was that across the Tees at Middleton, consisting of two common chains stretched across the river, and secured to the adjoining rocky banks; the span was 70 feet. To Captain Sir Samuel Brown, however, who had previously brought chain cables into use for ships, may be attributed the introduction into England of the improved system of the bar link, which is now so generally adopted. Brown, in 1818, first constructed a large model of 100 feet span, capable of supporting a carriage and horses, indeed adapted for general traffic. He afterwards constructed (1819), upon this principle, Union Bridge for general traffic across the Tweed, near Berwick; the span was 450 feet between the supporting towers, which were of masonry. He subsequently built another, of smaller dimensions, across the Tweed, at Dryburgh. He also constructed that at Montrose, one over the Hundred Feet river in the Fens, and others, and applied the same principle with effect for landing-piers at Brighton and Leith. This system was afterwards carried out to a far greater extent by Telford, in his great suspension bridge across the Menai, at Bangor, in 1818–20, so well described by Provis. It consists of three openings; the centre is 580 feet span, the deflection of the chain being 42 feet, and the two side openings are 260 feet span each; the platform of the roadway is 100 feet above high-water mark; the sustaining towers of masonry are 50 feet above the roadway, and are connected to the shore by three stone arches on one side, and four on the other, 52 feet 6 inches span each. There are 16 main chains 1770 feet long each, in sets of 4 each, suspended above each other, on each side of the roadway, which is 30 feet wide from out to out, divided into three parts, two for carriages, on the outside, 12 feet wide each, and one for foot-passengers, in the middle, 6 feet wide. Each main chain consists of 5 bars or links, 10 feet long each, by $3\frac{1}{2}$ inches and $1\frac{1}{2}$ inch, connected together by plates and pins, on Brown's system, the whole being properly secured to the solid rock on each side. The total suspended weight of the main opening is 644 tons. About the same time he constructed another, upon similar principles,

300 feet span, across the river Conway, at Conway. These are fine works, and will remain as lasting monuments to his fame. The recent structures of Hammersmith, across the Thames, and Shoreham, across the Adour, by Tierney Clark, who is now erecting another upon a grander scale, 700 feet span, across the Danube; and lastly, that of Brunel across the Thames, at Hungerford Market (1845), show the progress made in this class of structures, which are well-adapted for crossing large and deep rivers where economy is an object; great care, however, is necessary in proportioning the strength of the chains and their curve, the selection and manufacturing of the iron for them, and also in the connexion and bracing of the roadway platform, in order to ensure the greatest strength and solidity of construction; of this, the improvements to the Montrose Bridge, by Rendel, is a good example; and the system, besides others by different engineers, should be followed, as several disastrous failures have occurred from neglect of these important particulars.

Amongst variations of the system, that of Dredge may be mentioned.

The wire suspension system, although in extensive use on the Continent, the largest example of which is at Fribourg, in Switzerland, where a bridge has been constructed of 800 feet span, for carriages as well as foot-passengers, has been rarely used in this country. Although economical in the first cost, it requires constant attention, and it scarcely possesses sufficient durability for permanent structures.

WOODEN BRIDGES.

Little was formerly done in Britain beyond the common pile bridge. These were formed by rows of piles for piers, driven at short distances from each other, and connected together by straight girders planked across to form the roadway, with a wooden railing on each side. Of this kind of construction, the bridges of Londonderry, across the Foyle, Waterford, across the Suir, Battersea, Fulham and others, across the Thames, are examples. In some cases, this system was extended by adopting larger openings, having diagonal struts, or butting-pieces, between the underside of the girders and the piles forming the piers, in order to reduce the bearing of the girders, and thus give them greater stability. The straight trussed frame or girder, so much used in America, was employed by Rennie, to a considerable extent, as service bridges, during the construction of the Waterloo and Southwark bridges, in 1809–19, and at New London Bridge, in 1825–31, with openings of above 100 feet, capable of supporting the heaviest weights. The late Colonel By, of the Royal Engineers, gave an account of a

bridge of this description, said to have been built across the Terrebonne, a large river near Montreal, in Canada, 600 feet span between the piers. It is said that this was carried into effect, and actually stood for a short time; but in consequence of its having been badly constructed, it required heavy repairs, and whilst these were being effected the whole structure came down, and was carried away by the floods. The trussed system has been applied with considerable success in some well-constructed bridges across the Tyne, for the Newcastle and Carlisle Railway, by Blackmore, and in several other places. The system of Wiebiking, of combining small curved pieces of timber connected together in the form of an arch, adapted for large spans, was first introduced, I believe, on the Ancholme, in 1826, when a bridge of 100 feet span was constructed with complete success. This has been used by Green, in the viaducts for the Newcastle and North Shields Railway, and has been followed by others also. Price, long ago, proposed a similar system; but the scarcity and dearness of timber, and the prevalent use of iron, probably prevented its application before. The lattice bridge, of American origin, has latterly been introduced on the Birmingham and Gloucester Railway by Moorsom, and on the Dublin and Drogheda Railway by McNeil, and as they are economical and simple in their construction, they are applicable in some cases with advantage.

In the designing and constructing of bridges of stone, wood, cast and wrought iron, an accurate knowledge of the strength of materials is peculiarly important, nay absolutely indispensable; and the profession is much indebted to George Rénnie, who commenced a series of investigations on this subject in 1817, which were communicated to the Royal Society, and published in their Transactions in 1818. These experiments were amongst the first to determine with precision the absolute and relative strengths of materials, under the effects of tension and compression. He subsequently made above six hundred experiments in 1827 on the friction of plane and round surfaces, with and without unguents, under the different circumstances of time, surface and pressure, which were published in the Philosophical Transactions in 1828. In 1830 he also made experiments on the friction and resistance of fluids, which were published in 1831. Morin's experiments did not appear until 1834—Tredgold, Barlow, Fairbairn, Hodgkinson, Wood and others, have since carried these experiments to a greater extent.

Concrete, a mixture of gravel, sand, lime, and other cements in certain proportions, was well-known to the ancients, and in conjunction with the invaluable natural cement, Pozzolana, was applied with the greatest success in the then numerous moles and other submarine works, and its use has been still con-

tinued in Italy to the present day. Wren is said to have used it for a portion of the foundation of St. Paul's, where it was defective. Semple also alludes to it in 1776. Its use appears to have been discontinued for a time, but recently to have been resumed. Rennie proposed it for the foundation of the Penitentiary in 1811; Smirke and others followed in the same track, and now the employment of concrete for the foundations of buildings has become nearly universal wherever it is necessary.

Brick has been much used for bridges over canals and drains by Rennie, and in railway bridges by Stephenson, Cubitt, Locke, Rastrick and others; and latterly it has been carried to a far greater extent by Brunel in his bridge across the Thames at Maidenhead, for the Great Western Railway. It consists of two semi-elliptical arches, each 130 feet span, and rising 24 feet; they are built wholly of brick, in Roman cement.

Roman cement, discovered by Parker in 1796, is chiefly made from a stone found on the shores of the Isle of Sheppy, near Sheerness; it is burnt in a kiln, and when ground into fine powder, possesses the peculiar property of setting hard immediately, although exposed to water, which renders it very valuable in hydraulic works. It had been little used in public works until it was adopted by Rennie and others. It was extensively employed in the naval works at Sheerness and elsewhere, and is now universally made use of in buildings where immediate induration or setting is required, in order to prevent the action of water, or where any settlement from insistent weight would be injurious. Latterly Roman cement stone has been found at Harwich and other places. Aberthaw, Lyme, Barrow and other limestones also possess valuable properties for water-works. The success of buildings depends materially upon the cement or mortar employed; and much has been done by Smeaton, Rennie and Telford in the selection of the best lime, sand and other materials, in combining them in proper proportions for the respective parts of the works where they were employed, and in the application of machinery for the more thoroughly mixing up and incorporating the materials together. Great credit is also due to Higgins, Pasley, Donaldson, Smith and Godwin for their valuable experiments and treatises upon this important subject*.

Additional strength has been given to brick structures, by the introduction

* From the valuable researches of these authors it appears, that the hydraulic cements contain considerable portions of silica and alumina, and in some cases metallic oxides; and where natural hydraulic cements cannot be obtained, they may be produced artificially, by the combination of these ingredients in the proper proportions.

of bands of thin hoop iron between the courses; this improvement was first generally introduced by Sir M. I. Brunel.

TUNNELS.

Subterranean tunnels have been much used in inland navigation, particularly in the Duke of Bridgewater's Canal, some miles of which, at Worsley, are made under ground; in the Harecastle Tunnel, by Brindley, on the Trent and Mersey Canal, in 1776, which was rendered more convenient by Telford, in 1826, by adding another parallel to it, of larger dimensions; in the Huddersfield Canal, where there is a tunnel 5280 yards long; in the Braunston Tunnel, on the Grand Junction Canal, and many others: all of these, however, have been surpassed by the Tunnel under the Thames, at Rotherhithe, by Sir Isambard Brunel, which, for magnitude, boldness in the design, and ingenuity in the means of construction, as well as the extraordinary difficulties by which the work was attended, will long remain a lasting monument of the talents and perseverance of that celebrated and ingenious engineer. This extraordinary work was commenced in 1825; it consists of two arched openings 1200 feet in length, 14 feet span each, 16 feet 4 inches high, separated from each other by a pier 4 feet thick, having sixty-four lateral arches of 4 feet span, to communicate between the main openings, the whole being surrounded with massive walls. The external dimensions of the walls, including the openings, are 38 feet wide, and 22 feet high. It is approached at each end by a perpendicular shaft, 50 feet diameter, and 80 feet deep; but the tunnel was intended hereafter to be carried out to the surface of the adjoining streets, at such a moderate inclination that carriages could easily pass through it from both sides of the river. The crown of the tunnel is about 16 feet below the bed of the river. In order to carry into effect this very difficult work, unusual means and precautions were necessary. The ordinary wooden centre framing scarcely presented sufficient strength and connexion for that purpose. Brunel, accordingly, invented a cast-iron framing (which he termed a shield) sufficiently large to embrace the whole width and height of the intended structure, and divided into thirty-six compartments, each sufficiently large for a man to work in, yet capable of being closed to prevent the access of water when required; the whole was impelled forward by powerful screws, bearing upon the work behind, as it was finished. This ingenious contrivance was perfectly successful; and although the works were twice suspended by the irruption of the Thames, nevertheless the apertures were stopped by bags of clay and other ma-

terials, and the structure was continued with extraordinary perseverance until finally completed and opened to the public in 1843. The whole was constructed with bricks set in Roman cement, and cased inside with the same material; and it gives every prospect of permanence and solidity.

A tunnel under the Thames had been previously proposed at Rotherhithe by Trevethick, and had advanced to some distance under the river, when it was abandoned; also one by Dodd at Gravesend, which was scarcely commenced. A tunnel was also carried to a considerable extent under the Severn, at Newnham, but failed for want of funds.

Tunnels form part of the works of almost every considerable railway, and the art of constructing them with accuracy and expedition is now brought to great perfection. Amongst the most remarkable tunnels executed upon railways, may be mentioned that at Kilsby, 2398 yards long, on the Birmingham and London line, by Stephenson; that at Box Hill, 3195 yards long, on the Great Western Railway, by Brunel; and that on the Sheffield and Manchester line, 5280 yards long, by Locke; several others of great length are now in progress.

HARBOURS.

In the construction of harbours, Smeaton, as already observed, had pointed out the proper course, in his Reports on Lynn, Wells, Aberdeen, Dundee, Dunbar, Port Patrick, Sandwich, Scarborough, Sunderland, Workington, Rye, Dover, and others. Ramsgate harbour was originally designed by Labelye in 1744; it had been partly executed by others, and continued with little success through a tedious succession of years, with various changes of plan, until 1774, when it was placed under Smeaton's direction: he soon saw the evil arising from the constant accumulation of mud which threatened to fill it up, in consequence of there being no back-water or scouring power to remove it. He therefore divided the harbour into two parts by a cross wall; the part next the shore formed a basin of eleven acres, in which the water could be retained by means of a lock, and discharged through powerful sluices in the cross wall into the outer harbour at low water, and thus form an effectual scouring power for removing the mud. Here was the introduction of a new principle for the maintenance of harbours, which is so difficult on an alluvial coast, operated upon by the tides and currents; and although previously in use on the Continent, it is believed to be the first example of the kind in Great Britain. Smeaton afterwards continued the works,

and introduced an improved system of masonry; in 1788, he founded the outer and inner walls of the outer piers, below low water, by means of caissons or boxes of wood, and so far improved the diving-bell as to render it useful in carrying on the operations, although he did not build with it; and about the same time he used it for examining the foundations of the piers of Hexham bridge, one of which had partially sunk. The late Mr. Rennie, who after Smeaton's decease took charge of the works at Ramsgate, profiting by what had been done, carried out the system to a greater extent, by enlarging the sluices and making them of cast iron, the old ones being of wood and frequently out of repair; a greater quantity of water could then be discharged in the same time, when required, and thus act with greater effect; or the discharge could be prolonged, according to circumstances. The masonry also, which, although good for the early period at which it was constructed, had become dilapidated, was rebuilt, where requisite, in a much more substantial manner. The steam-dredging machine was also applied to remove that portion of the mud which could not be effected by the sluices. The diving-bell was afterwards perfected by Rennie, so as to be perfectly manageable, and being suspended from a frame worked by proper machinery, it could be raised and lowered, or moved laterally, in any direction, with facility and promptitude, either according to the directions of the diver within the bell, communicated by means of signals, made by striking the sides of the bell with a hammer, or given by the superintendent above. All the operations for preparing a foundation, and afterwards laying the prepared blocks of masonry upon it, could thus be performed with as much certainty below as above the water. Rennie first used his improved apparatus in 1813 for rebuilding the advanced East Pier Head at Ramsgate Harbour, which was founded 17 feet below low water of spring tides with complete success. The value of this invention for submarine operations was now completely established, and he afterwards employed it with advantage in founding the pier heads and outer walls of Holyhead, Howth, and Sheerness Harbours, and other works under his direction, and it is now generally adopted in all similar circumstances. The diving-helmets and dresses, improved by Deane, Bethell, Edwards, Seibe, and others, have also materially contributed to the success of submarine operations.

After Smeaton, numerous artificial harbours were designed and constructed, and natural ones improved; amongst the former may be mentioned Holyhead, Howth, and Kingstown; at the latter there is a depth of 26 feet at low water of spring tides, and an inclosed area of 250 acres at low water; which is the largest

harbour attempted in this country by Rennie. Here and at Howth he substituted the flat slope for the upright wall to resist the waves*, and introduced the plan of throwing down loose blocks of rubble, or unhewn stone, for forming the main body of the piers, allowing the slope or angle of repose, at which the materials would lie, to be formed by the sea. In his system of making low-water harbours, which, up to that period, were almost unknown in Great Britain, he adopted the plan of enclosing the area by piers composed of several straight arms or lengths, intersecting each other according to particular angles, instead of making them curved, which, in his opinion, only served to increase the action of the waves. In asylum harbours, when practicable, as at Kingstown, he preferred making the entrance open to the dangerous wind, thus rendering them more accessible for vessels in distress ; but in order to prevent the prejudicial effects of any waves which might roll into the harbours, he adopted the returning and inclined form of entrance, by which means increased facility of entrance and departure was also given. He also designed his harbours with a view to preserving the original depth, as far as practicable, which is a principle of the greatest importance, and ought not to be lost sight of. The artificial harbours of Ardrossan, the Troon, Peterhead, by Telford, Scarborough, by Chapman, Hartlepool, and others, are worthy of remark.

In the improvement of natural harbours, may be mentioned Sunderland, Berwick, Aberdeen, Dublin, Newry, Drogheda, Leith, Belfast, and others. The principle generally adopted has been to confine and direct the tidal and fresh waters, by piers, in proper and sufficient channels, whence they are discharged into the ocean, so as to enable them to act with greater effect in counteracting the baneful effects of the antagonist operations of the winds, waves and sand, brought in from the sea; also to increase, as far as practicable, the receptacle for tidal and fresh waters, and to dispose of them in such a manner that they shall act with effect in maintaining and preserving the channels. These operations, as in the case of the Clyde, are materially assisted by the employment of that invaluable auxiliary, the steam-dredging machine, which ought to be attached to every harbour. I must not omit to mention the breakwater in Plymouth Sound, by Rennie and Whidbey, which is the first and largest example of a detached mole or breakwater in this country. It is a mile long, constructed in a depth varying from five to eight fathoms at low water, formed of

* This system was latterly always adopted by Rennie and Telford in preference to the upright wall, as being better adapted to resist waves; and it has been invariably successful, wherever it has been properly carried into effect.

loose blocks of rubble, of all sizes, up to ten or twelve tons weight each, thrown into the sea to form their own base and slope, according to the action of the waves. The surface from low-water mark to its full height, which is 2 feet above high water, has been paved with masonry; and at the base of the sea slope, at the level of low water, there is a berm or benching to protect it. At the western extremity a light-house has been built, to point out the western or principal entrance to the Sound, and a beacon on the eastern extremity points out the east entrance. The whole of the work, except a portion of the masonry, which is granite, has been built of limestone, brought from the adjoining shores. The intention of the work was to protect the Sound against the heavy swell, which formerly used to roll in with considerable violence during strong westerly and south-westerly gales: this object has been completely obtained, and the roadstead has been rendered perfectly secure. The work has been eminently successful in every respect; for besides obtaining the desired protection, the original depth of water has been preserved, the facility of ingress and egress has not been diminished, but rather increased, and the cost has corresponded as nearly as possible with the original estimate.

Another class of harbours, called Floating or Wet Docks, for receiving merchant vessels out of the tide or sea-way, was first introduced at Liverpool about the year 1716, and wet docks have been since constructed in almost all the principal ports of the kingdom—viz. London, Bristol, Hull, Leith, Sunderland, as well as for the Royal Navy at Portsmouth, Plymouth, Sheerness, Chatham and Woolwich. The East and West India Docks, by Jessop, Rennie and Ralph Walker; the London, Leith and Dublin, by Rennie; St. Catherine's, London, by Telford; the New Docks at Liverpool, by Hartley; at Hull, by James Walker; at Cardiff, by Cubitt; at Newport, by Green; at Southampton, by Giles; and the great works now in progress at Birkenhead, on the Mersey, opposite Liverpool, and at Great Grimsby, by Rendel, are magnificent examples of private enterprise for facilitating the commerce of the empire. The design of Rennie for a grand naval arsenal on the Thames, at Northfleet, immediately above Gravesend, intended as a substitute for the imperfect naval establishments at Deptford, Woolwich, Sheerness and Chatham, is worthy of remark. This magnificent design consisted of six capacious basins, with a total surface of 600 acres within the walls, the largest being 4000 feet long and 1000 feet wide, and covering 87 acres; the whole to communicate with each other, and be provided with capacious quays, dry docks, building-slips and storehouses; steam machinery for manufacturing cordage, blocks, anchors, flour and bread, sawing

and converting timber, pumping, and working cranes; in fact, for almost every operation connected with the naval service, and so systematically arranged and disposed, that the required operations should succeed each other with the greatest despatch and economy, whether of time, labour, or cost. The estimate was £11,000,000, which was perhaps more than would have been required: any portion could have been executed as it was wanted, without interfering with the general plan. It is to be regretted that this plan was not carried into effect, for it would have repaid the cost in the increased economy of fitting out fleets; and since that period about £5,000,000 have been expended on the old establishments in the Thames and Medway, with a small degree of benefit, compared with what would have been obtained from Northfleet. His design also for the improvement and enlargement of Chatham Dockyard is worthy of remark. It consisted of a new channel to be made for the Medway below Rochester Bridge, and converting the bend of the river, in front of the Dockyard, into a magnificent floating dock of above 100 acres, and from thence making a canal, 1¼ mile long, 300 feet wide, and 30 feet deep, to the deep water in the Medway at Gillingham, by which means vessels of war of the largest class could come to the Dockyard with the whole of their armament, which they cannot do now; the course to sea would have been shortened, and the shallow water of the Medway avoided: thus Chatham Dockyard would have been rendered the most convenient and extensive in Europe, and its proximity to London by a railway would have rendered the yards at Deptford and Woolwich unnecessary. The estimate for this work was only £700,000, whereas since that time fully as much, if not more, has been spent upon Woolwich, with a very inferior result: indeed, it is not even too late to undertake this plan for Chatham now, and would well repay the expenditure. In designing and carrying into effect this important class of public works, so as to render them successful, a thorough knowledge of the nature and operation of tides, winds, currents, soundings, and all the departments of hydrography, physical geography, and geology is necessary; and in these sciences much is due to the exertions of Beaufort, Bullock, Washington, Denham, Buckland, De la Beche, Lyell, Greenough, Sedgwick, Murchison, Phillips, and others.

REVETMENTS, OR RETAINING WALLS.

These, until near the latter end of the last century, had been usually built with horizontal foundations and courses, the interior side being almost vertical, and

the exterior with a flat face and very little batter, or in many cases vertical. The curved face retaining wall was latterly introduced, with the foundation and courses inclining from the horizontal, so as to conform with the radius of curvature; this form of wall is preferable, in many cases, to the old, as combining greater strength with less section, and being more convenient in other respects, and was commonly used by Rennie in his various works, when applicable.

To whom the introduction of this improved form of wall is due it is difficult to ascertain with accuracy; but Rennie, Ralph Walker, and Jessop were amongst the first who brought it into use. A further improvement was made in the retaining walls used at Sheerness in 1815 by Rennie, where the foundation being composed of soft alluvial mud and quicksand, to a great depth, more than usual precautions were necessary to render the walls substantial and secure. The object was effected by enlarging the base, and making the interior hollow, like a caisson, with the bottom in the form of an inverted dome; the outer or river face being concave, and the foundation, for a certain width, laid reclining at right angles to a tangent from the curved face of the front of the wall; the remainder of the foundation was horizontal, and the back or land side of the wall was vertical. Thus there was both a front and back wall connected together by cross walls, forming one mass; the inverted arches or domes under the hollow spaces being filled with chalk and gravel concrete, and the whole resting upon a well-connected platform of piles and cross-beams and planking. By thus distributing the same quantity of materials over a greater surface, the vertical weight per square foot was reduced, and the desired stability was obtained upon this very difficult and treacherous foundation. Rennie had previously tried, with success, a wall of a similar principle, and under similar circumstances at Grimsby. General Bentham also tried a similar principle, about the same time, which was not so successful, in consequence of an unsuitable form and construction.

The coffer-dams which Rennie employed for constructing the walls at Sheerness are worthy of remark, as being the most extensive and difficult that had been constructed up to that period. The bottom being soft mud to a considerable depth, piles of 60 feet to 80 feet in length were necessary, and when driven and braced in their places as far as practicable, chain bars and raking-shores from the land were requisite, in order to counteract the alternate pressure inwards and falling outwards, occasioned by the badness of the foundation and the heavy shocks of the waves to which they were exposed. In order to break the effects of the sea during storms, he employed a series of old men-of-war hulks, to act as floating breakwaters; these were useful to a certain extent, so

long as they held firm in their places; but at times, during heavy gales, they dragged their moorings, and driving against the dams, occasioned considerable damage; upon the whole, however, they were useful*. In order to give greater security to the dams, and to prevent leakage, a considerable quantity of grooved and tongued sheathing-piles were necessary for the works; and to effect this, he invented a machine worked by a steam-engine, which answered the purpose effectually, at a cost of one-sixth of the price of manual labour; and as it was unsafe to withdraw any of the coffer-dam piles, he made another machine for cutting them off at the ground level, below low water, which was also found very useful.

The dams for founding the sea-locks of the Caledonian Canal at Fort William and near Inverness, by Telford, are worthy of remark. In the former case, great difficulties arose, in consequence of the foundation being rock, at some depth below low water; this was overcome by ingeniously securing the piles to the rock; and in the latter case, where the bottom was soft mud, the difficulty was obviated by bringing cargoes or masses of earth and clay from a considerable distance, and afterwards driving the piles through the made ground. The great dam, 1000 feet in length, for building the foundations of the river-wall and New Houses of Parliament, by James Walker, is another good example. The late Peter Ewart was among the first who introduced cast and wrought iron for dams, for piling in general, and for wharfs; it has been since employed by Walker, Sibley, Stevenson, and others, in many situations, with great success. At the Albion Mills, already mentioned as the first steam-mill constructed in 1785, by Watt and Rennie, on the banks of the Thames, close to Blackfriars Bridge, the foundation being soft mud and moving sand, inverted arches were formed upon the ground, between the foundation courses of the walls, so that the whole area of the building obtained support by the same weight resting upon an increased base.

DRAINAGE.

In works of draining extensive districts of low marsh or fen lands, the Romans, with their usual energy and ability, effected much, and the Po-dike, Caer-dike, and the embankment of the Thames, amongst other works, are good

* Floating breakwaters of timber have latterly been tried, as a substitute for more solid constructions, but they have not hitherto succeeded.

examples. After they left the country, it relapsed into its former state of barbarism, and so remained for ages, until the art of drainage may be said to have been lost. Upon its revival, the Dutch, from necessity, had become extremely skilful, and were celebrated throughout Europe at a remote period, almost before engineering commenced in Great Britain. On account of the proximity to England, and their experience in these kind of works, when it became a question of draining the extensive districts of low marshy land on the east coast of England bordering upon the Humber, the Witham, the Ancholme, the Welland, the Nene, and the Ouse, it was natural that recourse should be had to those who, from their skill and experience, had already acquired such reputation as the Dutch; accordingly we find, in the reign of Charles the First, (when it was determined to drain the great level of the fens, afterwards called the Bedford Level, from the name of the Earls of Bedford,) Cornelius Vermuyden came over from Holland, and after draining the level of Hatfield Chase, adjoining the Trent, and acquiring considerable celebrity and influence, was knighted by the king. He planned great works in 1640, at the Bedford Level, for Francis Earl of Bedford, but the execution of Vermuyden's plans were prevented by the Civil War, and were afterwards carried into effect by William, the successor to Francis, Earl of Bedford, after much discussion and controversy, and were successful in draining the level to a certain extent. The plan in 1651 consisted in placing a sluice across the River Ouse, at Denver, about 15 miles from the sea at Lynn, where the Ouse enters the Great Wash, so as to exclude the tidal waters, leaving the channel of the River Ouse, above that sluice, for discharging the fresh waters only; these it was proposed to conduct from all parts of the land by small lateral drains or canals, carried to the river in as direct courses as practicable, having sluices at their junction with the river, to prevent the floods from entering them and covering the adjacent lands. He also cut a new channel, about 20 miles long, called the Bedford, or Hundred Foot River, for a part of the River Ouse, from the point where Denver Sluice was erected, to the old channel of the Ouse, at Earith, where another stanch or sluice was placed for preventing the tide from going beyond that point.

Vermuyden considered that by adopting this plan, and having only the fresh waters to contend with, he would get rid of that most powerful enemy to drainage, the tide; and then, having only to deal with the fresh water, he anticipated no difficulty in accomplishing the complete drainage of the land. For a time the plan answered tolerably well, and effected considerable improvement in the drainage; but he overlooked the important facts, that the tidal

waters formed the most important agent in keeping open the channels of the rivers, in preserving a good outfall for the drainage waters to the sea; that by excluding the tidal waters, the channel of the rivers would suffer, in proportion to the quantity of water which was thus abstracted from them, and that thus in time they would become incapable of effectually discharging the drainage waters; that the outfalls of the rivers would also suffer in the same proportion, and then the marsh-land districts, depending upon them for their drainage, would revert to their former inefficient state; and so it happened with the Bedford Level. The mouth of the channel of the River Ouse, which is the chief outfall for the drainage of the district where the Bedford Level is situated, being deprived of its accustomed and natural scouring power of tidal water, became so obstructed by shoals, that the land waters could not pass off to the sea. In proportion as the drainage became defective in process of time, as it necessarily did under the system adopted, windmills were erected to work scoop-wheels, with a lift of 4 or 5 feet for raising the water out of the lateral canals into the river. In 1713, Denver Sluice was undermined and blown up by the floods, and the tide recovered, to a certain extent, its ancient receptacles; and if proper measures had then been adopted, both the drainage and the navigation would have been restored to an efficient state; but the sluice was rebuilt after a few years on the old system, and the drainage and navigation became deteriorated as before. During the past century the drainage of the Bedford Level, as well as other districts, has been submitted to, and has occupied in succession the attention of the ablest engineers of the day; among whom may be mentioned the names of Perry, Elstobb, Grundy, Golborne, Armstrong, Kinderly, Smeaton, Jessop, Chapman, Page, Robert and William Mylne, Huddart, Rennie, Telford, Walker, G. and J. Rennie, Cubitt, Rendel, and others.

Amongst the most remarkable operations of this nature, may be mentioned the works upon the river Ouse, for the purpose of improving the drainage and navigation, which had become seriously affected by the accumulation of sands at its mouth, and the abstraction of the tidal waters above mentioned. The principal defect existed immediately above the town of Lynn, where the river took an extraordinary bend almost at right angles to its general course, for a length of $5\frac{1}{2}$ miles, forming almost a semicircle, the diameter of which was only $2\frac{3}{4}$ miles; independently, moreover, of this circuitous course by which so much fall or inclination of the current was lost, the channel was so irregular and disproportionate in width, and so much encumbered with shifting sands, that the tidal and fresh waters were unable to force their way through them; thus the drain-

age waters were penned up above, and being unable to get off, formed a tranquil pool, which during floods frequently broke the banks and inundated the surrounding country, the channel, moreover, being deprived of its natural scour, silted up in the same proportion. In order to obviate this great and growing evil, the ablest engineers of the day were consulted, and they unanimously concurred in the opinion, that the only sure means of providing a remedy was to cut off the bend in the Ouse, by making the shortest channel between its two extremities. This plan was first proposed by Bridgeman, in the year 1724, and was subsequently recommended by the various engineers of the day who succeeded him. In the year 1792, an Act was passed, after great opposition, empowering a certain body of Commissioners to carry into effect this cut, which was called the Eau Brink Cut, the expenses of which, estimated at about £80,000, were to be defrayed by a tax of 4*d*. per acre on the middle and south levels of the Bedford Level, comprising about 300,000 acres of land drained by the Ouse. This great work was to have been carried into effect by Robert Mylne and Sir Thomas Hyde Page: but they disagreed as to the proper form and dimensions of the cut, and referred the matter to Captain Huddart, who decided between them; so much money, however, had been spent in litigation, that the tax which was levied to pay for its execution was exhausted. In 1817, another Act of Parliament was obtained, empowering certain Commissioners to raise additional and increased funds from the lands which it was supposed would be benefited by it, and the execution of the work with its branches was entrusted to the late Mr. Rennie, as the principal engineer. The Eau Brink Cut, which was executed according to the award of Huddart, and the works connected with it, were finished and opened on the 19th of July, 1821, and very beneficial effects, as had been anticipated, immediately followed; the extraordinary wet winter of 1821 which succeeded, proved its success beyond doubt; for soon after the cut was opened, the low-water line in the Ouse, immediately above it, fell five feet, which necessarily produced a corresponding increase in the fall or inclination in the current, and thus gave it increased velocity and power to scour away and remove the obstacles in the bed of the river, and to discharge a greater quantity of water in the same time, as well as a longer period for discharging it, to the great benefit of the country drained by it. The tidal waters, moreover, being freed from the shifting sands and circuitous course of the old channel, and being confined in one mass in the new direct channel, acted with greater effect: finding their way upwards, and becoming united with the fresh waters in enlarging and deepening the channel above, they kept it open to its proper dimensions,

and thus both the drainage and the navigation derived benefit from this great work. The improvement was carried still further, in adding one-third to the dimensions of the cut, particularly at the upper end; by this means an additional fall of about 2 feet 6 inches was obtained, making a total increase of about 7 feet 6 inches in the fall of the current at the upper end. The effect of these improvements has been to increase greatly the produce and value of upwards of 300,000 acres of land drained by the Ouse, which otherwise could not have been cultivated. The measure, like almost all other great improvements, encountered great opposition at the time, and in order to tranquillise the fears of some and satisfy the prejudices of others, various minor interior works were provided, such as locks and weirs, for penning up the water, most of which, but for existing prejudices, it would have been better to have dispensed with, and to have removed Denver sluice, raising the banks on the various rivers above, so as to have restored them to their natural state, and thus by admitting a greater quantity of tidal water, to have scoured out their channels, and thereby have enabled them to carry off the drainage waters more effectually.

A similar operation was executed by Telford and Rennie, on the river Nene, in 1829, at the Nene outfall, which commences about 6 miles below Wisbeach, and terminates at Skate's Corner, a length of nearly 5 miles, where it joins the great estuary of the Wash. The beneficial effects of this work have been very extraordinary; the low-water mark has been lowered 10 feet 6 inches, and a district of above 100,000 acres has been completely drained and brought into cultivation, which formerly for the greater part of the year was little better than a stagnant marsh; the navigation has been so much improved, that the tide rises 14 feet at Wisbeach, and vessels of 200 tons are now enabled to come up to that town, where previously the river was only navigable for small sloops; and at Sutton Bridge, 8 miles lower down, vessels of above 600 tons can arrive where formerly there was only water for vessels of 200 tons.

The river Nene having been thus improved, so as to enable it to carry off the tidal and fresh waters, an extensive plan for the interior drainage was designed and carried into effect by Telford, in 1830. It consisted of one main drain of proper dimensions, with two subsidiary drains of smaller capacity, extending above 20 miles, as far as Thorney, to bring down and discharge all the water from the low fen-land districts into the upper end of the new outfall, by means of a capacious new sluice with self-acting gates, which continues to discharge the water from the drains into the Nene, so long as the level of the water in the drain is higher than that of the river; but whenever the water in the river is higher,

the sluice-gates close and prevent the river water from entering. This plan of Telford's resembled one previously proposed by Rennie for the same object, but which was upon a more extensive scale, and was accompanied by the important addition of catch-water drains.

In 1806, Rennie proposed and carried into effect a complete system of drainage for an extensive district of fen-land, called the East, West, and Wildmore Fens, bordering upon the river Witham, into which they drained, about 10 miles above Boston. Rennie at once perceived the defects of the Witham as a means of drainage and navigation, and decided that until the river was improved by shortening its course and increasing the capacity of its channel, the complete drainage could not be effected. This plan he proposed, but the opposition was so strenuous that he was obliged to abandon it, and to carry his main drains into the river below the town of Boston: he divided the drains into two classes; one set he technically termed catch-water drains, which running along the base of the hills surrounding the low lands, intercepted all the high land waters, which, descending with great velocity, would soon have overwhelmed the low lands, in addition to the water falling upon them according to the extent of their surfaces. These high land waters were conducted by the catch-water drains into a main drain, which discharged the waters by a self-acting sluice into the Witham immediately below Boston; the low land waters, thus freed from the high land waters, were conducted by separate drains into another main drain at Hobhole, about 3 miles lower down the Witham, where there was more fall. By this means both classes of waters were discharged without interfering with each other; means were also secured of discharging all the water by the lower drain at Hobhole, in case it should be found necessary, which ultimately happened, and it was made of additional capacity for that object. The district was thus completely drained, and from a stagnant marsh was converted into corn-fields.

The Witham being left to itself, became silted up in 1827, as had been foreseen by Rennie, and the neap tides scarcely flowed above 3 to 4 feet at Boston. The channel was then improved as recommended by him, and the river is now in such a state that vessels drawing 12 and 14 feet arrive at Boston, and the whole country drained by the Witham has been proportionably benefited.

He proposed a similar plan for the improvement of the Great Bedford Level in 1811, the cost of which he estimated at £1,188,189; but unfortunately for that district it has never yet been carried into effect, although it would have amply repaid the outlay. The origin of the above system, it is believed, is due to Rennie, although it is said by some that the Romans employed catch-water drains,

and the Caer-dike is quoted as an example: it is however by no means clear whether it was not merely a navigable canal to connect the Nene and the Witham; at all events, the system, if ever it existed, had long been abandoned; and the revival, at least in modern times, is due to him. He also proposed the drainage of the Hatfield Chase and Ancholme districts, and Romney Marsh*, Holderness, and other districts upon similar principles, where drainage had been tried and had only partially succeeded.

After mature consideration and experience, it appears that the safest and most certain principles of drainage and navigation are,—the improvement of the channels and outfalls of the rivers, as far as may be practicable, for the free admission and discharge of the tidal and fresh waters; with interior drains, well laid out, of proper proportion and capacity for the low land, and catch-water drains for the high land waters; and, according to circumstances, the drainage and navigation may be combined or kept separate.

STEAM DRAINAGE.

Where natural drainage could not be effected, or was only imperfectly applied, recourse was had to windmills and scoop-wheels, as still used in Holland; these were always adopted until 1820, when Watt's steam-engine was successfully applied by Rennie to work a large scoop-wheel, for draining Bottisham Fen, near Ely. Subsequently this valuable system has been applied and extended by Glynn, Field, and others, to the great improvement of fen lands, by draining the water lower beneath the surface than could be done by windmills, which are now almost generally superseded by steam-engines; the latter can be used when required, whereas the windmills can only be employed when there is wind; and it frequently happens that calms prevail during rainy weather, at the very time when the mills are most wanted.

Whilst carrying out the improvements of the outfalls and mouths of rivers, it often occurs that large tracts of sand and mud may be converted into fine arable land, fit for agricultural purposes, by accelerating the natural accumulation of

* The difficulties here are peculiar, in consequence of the coast being surrounded with a broad belt of loose shingle, which renders it necessary to carry the drainage water through the sea banks by close tunnels, with valves at their outer extremities, so as to be forced open by the hydraulic pressure of the water. Dymchurch wall, or sea-bank, here is well worthy of remark: it was formed in the Dutch manner by stakes wattled together, and constantly required repair; it has since been faced with stone paving, at an inclination of about 6 to 1, which stands well, and resists effectually the heavy seas to which it is exposed.

warp, or alluvial matter, held in mechanical suspension by the water, and which, from the absence of proper measures, is otherwise carried away without producing any benefit. The works for this object and for improving the drainage and navigation, if properly conducted, consist generally in regulating and confining the channels of the rivers, through the sands below high-water mark, to one channel, for both the flood and ebb waters, and accelerating gradually the accumulation of alluvial deposit, by jetties and other light works adjacent to them: in proportion as the deposit accumulates, the works are raised until vegetation appears, which generally takes place about the level of high water of neap tides, and then the land is embanked from the sea. The system of warping or artificially soiling bad land where the levels will permit, has been practised for many years along the Trent, Ouse and Humber, with considerable success. The operation consists in admitting, through sluices and canals made for the purpose, the water charged with alluvial matter held in suspension, to the lands to be warped, which are surrounded with embankments; and after having deposited the alluvial matter the clear waters are conducted away again to the river; this process is repeated at intervals until the lands have been sufficiently warped, and thus lands which, in some cases, are situated several miles from the rivers, and were comparatively worth little, have become extremely valuable. If these operations be judiciously conducted, the outfalls of the rivers, and the harbours and drainage and navigation depending on them, may be greatly improved, and the land gained during the operation will, in many cases, amply repay the cost of gaining it. In Holland, and other countries, there is a great field open: much depends upon the situation and other local circumstances; considerable judgment and skill are required in selecting the districts, and in properly applying the system; but its consequences are so important that it is well worthy of the attention of engineers. A scheme of this kind upon an extensive scale is about to be carried into effect at the mouth of the Ouse and Nene, where above 30,000 acres of land will be gained, and great improvement will be effected in the drainage and navigation of the extensive districts drained by the Ouse and Nene. The same principle is applicable, in some cases, for converting shoals into effective breakwaters.

MACHINERY AND MANUFACTURES.

The improvement and extension of machinery and manufactures by new inventions and applications have been immense since the time of Smeaton. Pre-

vious to that period wood was almost exclusively used in the construction of machinery. Desaguliers, Leupold, Gravesande and other writers, have given descriptions of the best specimens of mills and machinery in use a century ago, but they were very defective, both in proportion and construction, when compared with modern machinery for similar purposes. The introduction of cast iron by Smeaton in 1754, was a great step in advance. He began by employing cast iron for the axis of one of his earliest windmills, in 1754; then in 1769, for the shaft of a water-wheel, and the main-wheel attached to it, for boring cannon at Carron; cast iron afterwards was generally adopted for axes, but as some of them, which were improperly made, gave way, the application of cast iron in other machinery was in some measure retarded, until Watt applied his steam-engine to drive mills. The Albion Mills, constructed by Rennie in 1784, and worked by Watt's steam-engine, may be considered as the first complete example of the employment of iron in every part of machinery, except for the teeth of some of the wheels, which were made of hard wood, for working into the iron teeth of other wheels; that example also showing the true form of teeth, with a fine pitch, and adequate depth and breadth and adjustment with each other, so as to work well together with the least friction, and the use of bevel gear, which is the perfection of modern millwork.

The great improvement effected in the design, proportion, and construction of millwork, together with the steam-engine, enabled machinery to be driven with greater velocity, increased action, and diminished friction, and thus greater effect was produced with the same amount of power.

We are indebted to our honorary member, Professor Willis, for his able investigation of the teeth of wheels, and to Whewell, Moseley, Jamieson, G. Rennie (for his new edition of Buchanan), and others, for their valuable treatises on mechanical and engineering subjects.

The invention of the spinning-jenny by Hargreaves, in 1767, and of the means of drawing out the fibres of cotton between successive pairs of revolving rollers in the water-twist spinning, by Arkwright, in 1769, followed by his system of machinery for carding and preparing fibres of cotton for spinning, in 1775, occasioned a complete revolution in the arts of manufacturing, and led to the establishment of the factory system, with its self-acting machinery. A somewhat similar system had, however, been introduced in the Silk Mills at Derby nearly half a century before; but inasmuch as silk naturally consists of a series of fine threads, it is only necessary to twist or retwist them, in order to combine them together, which is a very simple operation, compared with forming the

short detached fibres of cotton into a thread, without the aid of the hand to guide them; and to accomplish this by machinery was extremely difficult; it was, however, very ingeniously overcome by Hargreaves and Arkwright in different ways, both of which were combined together by Crompton in the mule in 1771. Arkwright's water-spinning was subsequently simplified into what is technically termed throstle-spinning, and together with his preparing machinery of 1775, was adopted for spinning worsted by Toplis, and for flax by Marshall. The carding machinery was also adopted, with suitable modifications, for preparing short wool, Hargreaves' spinning-jenny being used for spinning it into yarn for woollen cloth. The mule for a long while was only employed for cotton, but was adapted by Kelly in 1790, to be partly worked by power in aid of manual labour, and was soon after improved so as to spin extremely fine threads.

All these valuable inventions, together with a multiplicity of other ingenious contrivances connected with the factory system, were completed and brought into extensive use in the short period of twenty years. Machinery for printing calico was introduced by Peel, and perfected by others. Watt, in 1787, introduced chemical bleaching, which was afterwards carried to great perfection by Tennant. Cartwright, in 1787, invented cloth-weaving by power, although it was not brought into use until twenty years after, and, in 1790, he invented machinery for combing and preparing long wool, in preparation for being spun into worsted. Machinery for dressing woollen cloth by teazles was perfected, and Harmer invented machinery for shearing it in 1787. This has since been carried to greater perfection by Lewis. Bramah, in 1796, introduced the hydraulic press, which furnished the means of pressing cloth, books, papers, and other articles with a degree of force which could be accomplished by no other means, and its general adoption has been of great service. Self-acting machines for making button-shanks were invented by Heaton. Boulton's large manufactory at Soho contained many inventions besides those of Watt. He invented machinery for coining money by steam power in 1790, and erected a complete establishment at Soho, where, for a long time, he executed contracts for coining money for the British, and various foreign governments. His plan for stamping the pieces, consisted in exhausting air by pumps worked by a steam-engine, from vessels properly adapted for the purpose, and connected by valves with air cylinders, having pistons working the balance-beams of the coining-presses. By opening a valve, air is exhausted from within the cylinder, and the atmospheric pressure acting upon the piston, turns down the screw of the press which stamps the coin; by re-admitting air, the piston rises and with it the

screw, thus producing an alternate rising and falling motion so as to strike from 50 to 60 pieces per minute; as the screw rises and falls, it works a feeding apparatus for supplying blank pieces, ready prepared for stamping, and as fast as one piece is stamped it is pushed off the die, and is replaced by another. The apparatus for cutting out the blank pieces is of a similar description; the whole is self-acting, and is a most beautiful and ingenious contrivance. These improvements were introduced into the Royal Mint, at Tower Hill, which was constructed in 1810, under the direction of Messrs. Boulton and Watt, who furnished the steam-engines and the coining machinery. The rolling machinery by Rennie, and the equalizing machinery of Barton, constructed by Maudslay, complete this magnificent establishment. At St. Petersburg, Copenhagen, Calcutta, and Bombay, Messrs. Boulton and Watt erected similar establishments, with rolling-mills by Rennie, at the two latter places.

The whole of the above ingenious and valuable inventions, except power-weaving, had been fully carried out and brought into successful practice before the end of last century. The brilliant results which were obtained from these inventions excited, in an intense degree, the skill and ingenuity of a host of able mechanicians in the various departments above mentioned. The most minute operations were reduced to system by the use of machines, and the high profits derived from manufacturing by machinery, while the prices of the articles continued the same as those formerly produced by manual labour, occasioned a readiness before unknown to adopt all new machines, as well as to extend and improve them.

WATER-WHEELS.

The general introduction of self-acting machines induced the construction of more extensive mills of all kinds, and rendered necessary the use of more powerful and better regulated prime movers. Water-wheels were employed as the moving power at the early establishments of Cromford, Belper, Matlock, Bakewell, Lanark, Cattran, Deanstone, &c.; and when the governor was afterwards applied to water-wheels by Strutt, at Belper, the motion and power were regulated with a degree of uniformity almost equal to that of the steam-engine, and water was rendered as perfect a moving power as its nature admitted of. Rennie, it is believed, first applied the descending shuttle, by which the flow of water is regulated over its upper edge, so as to obtain the full benefit of the fall, instead of passing under the shuttle as formerly, whereby some of the fall is lost.

He improved the construction of the wheel, increased the width and diminished the depth of the buckets, at the same time augmenting the velocity of the periphery from 3 feet to 5 feet per second. By these means nearly 75 per cent. of the power was realized. Strutt's improvements in water-wheels, executed by Hewes, consist in making them with slender iron arms and oblique tie rods, with segments of teeth on the circumference of the wheel, turning pinions with nearly the same velocity as cranks of steam-engines, and rendering them almost equally applicable. In this department Donkin and Fairbairn have also taken a conspicuous part.

The turbine, or a modification of the horizontal water-wheel, by Fourneyron, has latterly been introduced into this country from France, with, it is said, considerable success. The governor had been applied to windmills by Hooper, in 1789, and soon after Watt adapted it to his rotative steam-engine, which was thereby rendered applicable for turning mills, and its superiority to water, and every other power then known, became manifest. The uniformity and certainty of the movement, its capability of extension to any amount, its applicability to any situation, rendered its adoption almost universal, and extended the sphere of manufacturing operations from the weaver's cottage and the banks of the lonely stream, to large populous towns, such as Manchester, Leeds, Macclesfield, and other places, wherever circumstances, independent of water, were favourable for their adoption.

The concentration of manufacturing operations caused a number of small machines to be substituted for those formerly impelled by hand in workmen's cottages, and brought together in large buildings adapted for that purpose, and worked by one great moving power, and so combined with each other and the building, as to render a spinning mill, with its water-wheel or steam-engine, and all its accessories, one vast and complicated machine. A new school for mechanics was thus formed, in which far greater power than had ever before been applied to machinery, was to be distributed amongst a number of delicate machines of the greatest variety of form and complexity, with some parts minute like clock-work, requiring every gradation of force to drive them, and corresponding strength in some for resisting the largest and others the smallest impulse. A new and extended field of inquiry and observation was thereby produced, which brought forward artists of every description to contribute their aid, as to one common stock of knowledge, for the advancement of the new system of manufacturing, as well for the invention of new machines and processes as for the multiplication and improvement of those previously invented. The ingenious

and valuable labours of the great mechanicians of the last century have been most ably continued by their successors, many of whom are, or have been, our contemporaries, and who, with a greatly extended sphere of application, have advanced in the career of improvement with an almost unparalleled rapidity.

Many new machines have been invented, and most of those in daily use have been rendered self-acting or automatical, so as to require no further aid from man, than the mere act of presenting the materials to them to be manufactured, directing their progress through the machine, and disposing of them afterwards.

The power loom, invented by Cartwright, in 1784, was afterwards improved by Austin, Miller, Horrocks, M'Adam, Lane, Bowman, and others, and its employment greatly extended. Machinery for making ropes and cordage was invented by Cartwright, Grimshaw, Chapman, and others, and subsequently carried to great perfection by Huddart, as exhibited in the establishment of Turner, Huddart, and Co., at Limehouse. This ingenious and valuable invention consisted in regulating and adapting the lengths of the different yarns or threads composing the rope, so that each might bear an equal strain, which could not be done on the old system. To effect this, a series of bobbins, with the proper lengths of yarns wound upon them, were placed in a frame of a crescent form, and the yarns from these bobbins were conducted through holes in a vertical guiding plate, having those holes arranged in concentric circles; from thence the yarns passed through a vessel of liquid tar or pitch, and then through a single hole of the required gauge, on to a large reel mounted in an oblong frame, to which a rotatory motion about a horizontal axis was communicated for twisting all the yarns together into a strand, and also a circular motion of the reel at right angles to that of the frame, for winding the strand upon the reel, as fast as they were wound off the bobbins; a guide was attached which regulated the winding. The whole was worked by one of Watt's steam-engines. By this beautifully-contrived piece of mechanism, the whole of the yarns were twisted into a strand of the required dimensions. The pitch and tar employed was used either cold or warm, and derived the application of warm or cold register cordage accordingly. The cables were formed by a larger machine, combining three of the above-described frames together, each having one of the strands to form the cable wound upon its reel; but the axes of the three frames, instead of being horizontal, as in the first case, were vertical, and all mounted in one large frame, which received a rotatory motion, about a vertical axis of its own, and carrying round the minor frames combined within it in order to twist the three strands together. The several strands were unwound from the reels, in the minor

frames, as fast as the three were twisted together into the intended cable, which was drawn upwards between pairs of grooved rollers, disposed above the centre of the main frame, and the cable was conducted away by the same machinery and coiled up for use. Nothing could be more striking than the spectacle of one of these magnificent machines, resembling a great orrery in motion, pursuing its silent yet resistless course, producing the means of securing at anchor the gigantic vessel of war against the raging tempests of the ocean. This magnificent machinery, after returning a handsome reward to its ingenious inventor, and the enterprising capitalists who erected it, was bought by Government, and erected at the Royal Arsenal, Deptford. Chapman's rope machinery, and Curr's for making flat ropes, chiefly used for mines, as well as a new machine, lately introduced at Portsmouth from France, said to be the invention of Hubert, are worthy of notice.

Dyer's machines for making cards, for cotton and wool, and others for cutting nails; Wilkinson's, for making weavers' reeds; the self-acting mules of Eaton, Roberts, Smith and others; those for weaving bobbin-net lace, by Heathcoat, Morley and others; Holdsworth's, Dyer's, and other improved machines for preparing cotton rovings; Marshall's, P. Fairbairn's, and other machines for flax, are all ingenious and important inventions of self-acting machinery, well-calculated to improve, expedite, and economise the manufacture of the various articles for which they were intended. Amongst the same class may be mentioned the curious inventions and improvements of Didot, Donkin, Fourdrinier, Dickinson, Crompton, Towgood, Ibotson, Kœnig, Nicholson, Tilloch, Congreve, Stanhope, Cowper, Applegarth, Spottiswood and others, for making and drying paper, and printing by steam; Oldham's various contrivances for printing bank-notes at the banks of England and Ireland; Lowry's, Maudslay's, Perkins', and other machines for engraving on metal plates; Hollingdrake's method of casting copper under pressure, for engraving; Brunel's block machinery, executed by Maudslay, at Portsmouth, by which every operation is performed, from the sawing of the rough piece of wood until the perfect completion of the block for naval purposes; his saw-mills at Chatham and Woolwich; Bramah's planing machine at Woolwich; Wilkinson's machine for boring large cylinders are splendid specimens of machinery; neither must we omit Watt's simple operation of making small leaden shot, by pouring melted lead through holes in a cullender at the top of a lofty tower, when they assume a spherical form in cooling, as they fall through the air, and finally into cold water below. Leaden bullets are compressed into a spherical form with great

solidity by self-acting machines by Napier. The manufacture of crown and plate glass has been improved, and promises great extension; in this latter branch, Green, Pellatt, Chance and others, are making great progress. The universal and widely-extended application of machinery to every manufacturing operation rendered a corresponding activity and means of supplying the increased demand for it absolutely necessary; and additional means of making machines have been invented. Self-acting turning lathes, with slide rests, planing machines for metals, also for screwing bolts and nuts, were introduced by Fox; mortising machines, similar to those of Brunel, were adapted by Sharp and Roberts for metals, and shaping machines by Penn; these have been improved by Whitworth, Nasmyth and others, by whom also new ones have been invented. The former has introduced an ingenious adaptation of machinery for sweeping roads and streets, and which, from its efficiency, is coming into general use; and to the latter we are indebted for the steam-hammer and steam pile-driving machine, which serve materially to economise and facilitate these operations. Rennie, as far back as 1801, had applied steam for driving the piles of the coffer-dam for the London Docks; it has since been applied at Sunderland for a similar purpose, and he proposed it for working the cranes there as well as at the West India Docks; but it was not adopted. Otis' American machines for excavation have been tried, but are not as yet much employed. The invention and application of these various new and ingenious contrivances, furnished the means of executing machinery with a degree of economy and accuracy, which, without them, could never have been attempted. With the advancement of machinery, the art of founding in iron, which commenced at Carron, soon became an indispensable part of machine-making. In this department Boulton and Watt took the lead, in consequence of the demands for their steam-engine, and made great improvements in it, which were afterwards followed by Maudslay (particularly), and by others. The working in metal towards the commencement of this century thus became so much facilitated, that it was generally adopted, instead of wood, for the framing and moving parts of machinery; and castings in iron, of excellent quality, could be obtained in any number exactly like each other, so as to be fitted together with great facility. In the progress of modern improvements, wrought or forged iron came into more general use, and was substituted for cast iron in many cases, such as for railways, suspension bridges, tie beams, and roofs for buildings, various parts of steam-engines, mill-work, and machines of different kinds; and in some instances steel has been adopted. As the improvement in machinery for manufacturing

advanced, so did the arrangement, convenience, economy, and construction of the buildings in which it was contained; fire-proof arching for floors, with cast-iron beams, wrought-iron ties, cast-iron columns, and wrought and cast-iron framing for roofs, window-frames, and every other part where the introduction of metal was practicable; in these improvements, Strutt, Rennie and others took a leading part. Apparatus for warming buildings by heated air was adopted by Strutt and Sylvester; and by steam, which had been employed by Smeaton for drying gunpowder, was generally introduced by Snodgrass in 1798, and improved by Houldsworth and Creighton. This system has been more recently succeeded by that of heating the air by contact with pipes or vessels, in which a circulation is kept up, as practised by Price, Manby, Perkins, Haden and others. These and many other improvements have been introduced, and combined in the most scientific manner, in the great cotton-mills of Messrs. Phillips and Lee, M'Connell and Kennedy, Houldsworth, Birley, and numerous others at Manchester; Messrs. Horrocks' at Preston, Strutt's at Belper, the flax-mills of Marshall, and the woollen-mills of Messrs. Gott at Leeds, and of Wilkins near Bath, the silk-mills of Grote at Yarmouth, the lace-manufactories of Heathcoat at Tiverton, Boden and Morley at Derby, and Fisher at Nottingham, Cartwright and Warner's steam-power stocking-weaving manufactory at Loughborough, and many other magnificent establishments all over the kingdom. The workshops of Fox, Nasmyth, Sharpe, Roberts, Whitworth and others, for making tools; the steam-engine and machine manufactories of Boulton and Watt, Fawcett, Bury, the Butterly Company, Stephenson, Hawthorn, Donkin, Hall, Fairbairn, Hick, Napier, Miller and Ravenhill, Maudslay and Field, Penn, Rennie, Seaward, &c., are a few of the vast establishments which abound, and which fill us with astonishment at the immense productive powers of this country; we are at a loss which to admire most, the genius and skill which have designed them, the energy and talent which direct them, or the capital which has brought them into operation. For accounts of many of the numerous branches of the immense manufacturing industry of Great Britain, we are indebted to Farey's articles in the Cyclopædia of Rees, the Encyclopædia of Brewster, and the Supplement to the Encyclopædia Britannica, also to those of Babbage and Barlow in the Encyclopædia Metropolitana, and likewise to Dr. Ure.

The improvement and extension of manufactures required a constant, active, and steady communication between the several districts where they were carried on, and soon produced a corresponding improvement in the roads, railways, canals, rivers and ports. The cost of every article was reduced to the greatest

nicety, and economy was carried to the minutest degree; being so intimately connected together, the extension of the one kept pace with the other. The same may be said of the arts of mining and metallurgy, by which coals for fuel and metals for manufactures are furnished to the different establishments.

WATERWORKS.

In the supply of that important necessary of life—water, which was so much studied by the ancients, but so greatly neglected in the middle ages, great progress has been made in modern times. Spring-water was formerly conveyed to public reservoirs in the City of London by leaden pipes, from various springs in the vicinity: viz. from Tyburn in 1236, from Highbury in 1438, from Hackney in 1535, from Hampstead in 1543, and from Hoxton in 1546. For these useful works the citizens were indebted to the munificence of several Lord Mayors and other individuals; but those of Hampstead and Highgate are the only ones now remaining. The open watercourse or conduit from Dartmoor, 24 miles long, for supplying Plymouth with water, commenced by Sir Francis Drake in the reign of Elizabeth; and the New River, for the supply of London, 39 miles long, 28 feet wide, and 4 feet deep, falling 3 inches in a mile, by Sir Hugh Middleton in 1613, are considerable works of the kind, and were planned and executed at the cost of those distinguished individuals. Middleton was, in fact, ruined by it, and adopted the profession of an engineer and surveyor to obtain a livelihood.

London Bridge Waterworks were commenced by Morice in 1582, with water-wheels turned by the flood and ebb current of the Thames, passing through the purposely-contracted arches of Old London Bridge, and working pumps for the supply of water to the metropolis; it was the earliest example of public water service by pumps and mechanical power, which enabled water to be distributed in pipes to dwelling-houses. Previously, water had only been supplied to public cisterns, from whence it was conveyed, at great expense and inconvenience, in buckets and water-carts. In addition to the London Bridge and New River, several minor establishments of the same kind were afterwards erected on the banks of the Thames, to supply separate districts in their immediate vicinity. Some were worked by water-wheels on the sewers which discharged themselves into the Thames, others by horses, and one by a wind-mill. That at Broken Wharf in 1594, at Shadwell and York Buildings, worked by horses, and at Chelsea by water-wheels, may be mentioned. Early in last century, when the old cisterns had nearly disappeared, and water was supplied to the dwellings, a

great improvement took place, by the application of the steam-engine (which had then begun to develope its extraordinary powers) to the York Buildings Waterworks, by Savery, in 1710, and afterwards by Newcomen, in 1730. Newcomen's engines were subsequently applied at Chelsea, Shadwell, Stratford, London Bridge, and the New River Waterworks. As soon as Watt had brought his improvements into operation for pumping water, his engines were applied at each of the above waterworks by degrees, in addition to the old engines; thus a comparison between them could easily be made, and soon showed the superiority of Watt's engine in every respect. They were thus applied at Shadwell and Chelsea Waterworks in 1778, at London Bridge and Lambeth soon after, and at the York Buildings in 1804. The usual mode for the old engines was to pump the water into a cistern, at the top of a high tower, and from thence it descended through pipes to the districts and buildings where it was required; the engine was thus always kept to its full load, whether necessary or not, and a waste of power ensued. Air-vessels were afterwards added to the pumps at Chelsea, and subsequently became general; the air in the vessels being compressed, acted by expansion and contraction on the water, so as to force it with regularity through the pipes, without going up to the cistern. Smeaton, who had constructed water-wheels for pumping at Stratford in 1763, and at London Bridge in 1767, where towers were employed, afterwards became the principal proprietor of the Deptford Waterworks, and in 1773 constructed a water-wheel for pumping water from the Ravensbourne without a tower. The machine is still in existence, although steam-engines have been subsequently applied. About 1810, Boulton and Watt's improved pumping-engines, constructed wholly of metal, and erected in handsome substantial buildings of brick and stone, with large air-vessels for pumping direct into the pipes, became generally adopted at all the London waterworks; cast-iron pipes were substituted for the old ones of wood. The new engines being more powerful, and the cast-iron pipes stronger, enabled water to be distributed to cisterns on the tops of dwelling-houses, hence denominated the high service. Stone pipes were tried at the Grand Junction Waterworks, but failed, and iron pipes were substituted. Filtering reservoirs upon a large scale were constructed at Chelsea by Simpson in 1830, and subsequently at other places, with complete success, and are now universally employed. The water is now generally taken from the Thames above the town, where it is least adulterated. The old waterworks lower down the river, viz. York Buildings, London Bridge, the Borough and Shadwell, have been abandoned, and new places chosen at Hammersmith and Brentford, higher up the river, and at Old

Ford upon the river Lea; the river water is received into capacious settling, or filtering reservoirs, and distributed by steam-engines to the respective districts. Latterly, powerful condensing steam-engines, very similar to Watt's, but worked by high-pressure steam with great expansive action, on the system introduced by Woolf, in Cornwall, for deep mines, were introduced by Wickstead, in 1840, at the East London Waterworks, and have since been adopted by other Companies with advantage in saving fuel. The double cylinder high-pressure condensing engine, with great expansive action, on the s ystem of Hornblower, has also been introduced by Woolf, Hall, and Rennie, and applied to work mills with success. Waterworks, similar to those in the metropolis, have been erected at Edinburgh, Glasgow, Dublin, Manchester, Liverpool, and all the principal towns in the kingdom. At Glasgow, one of the last engineering efforts of Watt was to suggest the idea of laying a pipe under the Clyde, to bring water to the city from the opposite side of the river: this was to have been effected by making the pipe with flexible ball-and-socket joints, uniting the whole together in one piece, and closing it at each end, floating it to its position, and sinking it. Rennie effected a similar operation at York Buildings in 1810. The increased means for the supply of water, and the economy and punctuality with which it is distributed, have occasioned a greater consumption, and induced a degree of cleanliness throughout all classes, which has tended to augment the comfort and health of the community. Still the system is capable of improvement; larger reservoirs and more copious supplies are necessary.

Artesian wells, which appear to have been known to the ancients, and have been common in France and Italy, were introduced into this country about the year 1790, it is said, by Vulliamy, near London. The system consists in boring holes or wells through the superincumbent strata, impervious to water, until they reach the porous strata, where water abounds: the pressure then acting according to the level from whence the water is derived, forces it upwards through the holes, frequently to some height above the surface; these have since been multiplied all over the kingdom during the present century, and latterly in Trafalgar Square, for supplying the first public fountains which have been erected in the metropolis. These fountains, though upon a small scale, are a beginning; and it may be hoped that this example will be generally followed for the ornament of this great city; which, although perhaps the best supplied with water in the world, has not been adorned with fountains, which are so general, and are constructed upon such a grand scale at Paris, Rome and almost all the other great cities in Europe, adding so much to their magnificence and salubrity. In carry-

ing out the improvements above-mentioned for the supply of water, the names of Smeaton, Watt, Mylne, Rennie, Telford, Simpson, Bateman, Anderson, Clark, Wickstead, Walker, Martin and others, must not be forgotten; and we shall no doubt witness efforts upon a still greater scale in future. Projects for bringing a large supply from the Thames, above Windsor, by Rennie; also from the Colne and Wandle, and Darenth and elsewhere, by Telford, Rennie and others, have long been in agitation, and sooner or later may be effected with advantage to the metropolis.

SEWAGE.

Connected with the supply of water for domestic purposes, we must not omit the important subject of sewage or surface drainage, upon the due operation of which the health of the community so much depends. Sewers appear to have attracted notice at an early period, and during the reign of Henry VIII. commissioners were appointed with extensive powers to levy rates for, and to see them properly carried into effect; but until underground or covered sewers were adopted, all the surface water from the adjacent hills and country, as well as the refuse from the buildings, was discharged into open ditches and street gutters, which, passing through the centre of the town, accumulated, and occasionally remaining stagnant for a considerable period, produced a degree of effluvia and malaria extremely prejudicial to the health of the inhabitants. This was remedied, to a certain extent, by covering over the open drains; but the bottom of these were not low enough, and the want of surface drains continued. By degrees, covered sewers, of enlarged capacity, entirely of brickwork, were introduced; the importance of the subject then became duly appreciated and studied; sewers were laid out upon a general and enlarged system; main, subsidiary and surface drains, and cesspools of a proper form, construction and capacity, adapted to each other, and to the several districts they were to drain, were designed, and in many cases carried into effect. The subject is still under consideration, and improvements are being daily effected, although much still remains to be done in the form, capacity, inclination, distribution and arrangement of sewers, not only in the metropolis*, but in almost all the principal towns of the kingdom, before the system can be said to be complete. The removal of Old London Bridge, by which a fall of about 5 feet at low water has been gained, has been of immense advantage in improving the drainage of the metropolis; and it only remains for this great improvement to be carried out further, by removing the

* There are nearly 500 miles of covered sewers in the metropolis.

shoals and regulating the high and low water channel of the river, by dredging and other means, but to be cautious in contracting the width; it is greatly to be desired that this important work should be speedily carried into effect, upon a general scientific system, which, if properly done, would confer the greatest benefits upon the extensive and populous districts, draining into and bordering upon the Thames, as well as the navigation of this noble river, upon the proper maintenance of which the immense commerce, health and prosperity of this great metropolis, and its adjoining populous vicinity, depends. In the improvements of sewerage, Cubitt, Barry, Donaldson, Gwilt, Hardwick, Nash, Smirke, Soane, Walker, Rennie, Roe and others, have been conspicuous.

GAS.

It is difficult to point out with accuracy the date of the invention and introduction of that invaluable substitute for daylight, or artificial lighting, carburetted hydrogen gas. It is generally believed, however, that it may be attributed to William Murdoch, soon after he succeeded to the management of Boulton and Watt's steam-engine works at Soho, although the inflammable properties of that gas had been long known. Murdoch's first apparatus was erected at Soho, and he successfully illuminated that establishment with it in 1802, in celebration of the Peace of Amiens; he afterwards constructed similar apparatus on a large scale at Leeds, for lighting Messrs. Gotts' woollen manufactory, and for Messrs. Phillips and Lee at Manchester, and published an account of it in the "Philosophical Transactions" for 1808. Clegg, who was brought up at Soho, also published an account of it in the "Transactions of the Society of Arts" in the same year. It was subsequently, by degrees, introduced into several large manufactories in Lancashire; Winsor afterwards exhibited it in Pall Mall, where it excited a good deal of attention; but the general application of gas for lighting towns was for some time retarded, in consequence of the failure of several attempts by inexperienced persons, which prejudiced the public against it, so that it was not until the year 1813 that apparatus of efficient and proper construction was made, and erected in London by Clegg, Farey and Manby, upon the same principle as originally introduced by Murdoch. The employment of gas for lighting towns and buildings has now become almost universal here as well as on the Continent. It is manufactured by distillation from coal in cast iron or clay retorts, and collected in immense gasometers, some of them 100 feet diameter, 44 feet deep, and capable of containing 390,000 cubic feet; thence it is

distributed through cast and wrought-iron pipes under properly regulated pressure many miles from the place where it is made; and self-acting meters, invented by Clegg, are applied at each building and district, in order to ascertain the amount consumed. It is purified by lime, sulphuric acid, &c., and its brilliancy is augmented by naphtha. In the various contrivances and details of the apparatus, and in the processes for manufacturing it, as well as in the economy of management, many improvements have been made by Clegg, Lowe, Manby, Philipps, Croll, Crosly, Hedley, Edge and others. When we compare the present mode of lighting towns and public buildings with gas, with the old system of oil lighting thirty years ago (even allowing that to have been a vast improvement upon the custom of our ancestors), we are astonished at the amelioration, and can scarcely comprehend how we could have gone on so long without it. Thus we find that the general adoption of every great improvement creates a refinement and fastidiousness of taste which stimulate others, so that we can no longer tolerate those imperfections which in a less advanced state of civilization were passed over unnoticed. The introduction of oil gas by John Taylor, and by Taylor and Martineau; Gordon's system of condensing gas into close vessels for rendering it portable; and resin gas by Daniell, must not be forgotten, on account of the superior light produced from those substances, although it has been superseded by the more economical coal gas; and when naphthalized on Lowe's plan, its light appears so pure as scarcely to be susceptible of improvement. Gas for lighting on an extensive scale was introduced into France by Manby in 1820, and has since become general on the Continent. The use of gas-light in private dwelling-houses is gradually extending, and as the objections of smoke, bad smell, and risk of explosion are fast disappearing before the exertions of the modern improvers, will become more general; the ingenious contrivance of Faraday, conveying away by pipes all the products of combustion, is worthy of notice. Clark and M'Neil's, and other burners, which ensure more perfect combustion, are decided improvements.

The employment of gas for Lighthouses promises important results; for there, almost any reasonable degree of cost and trouble in perfecting the light, so that it may be rendered more distinctly visible at greater distances at sea, will be amply repaid; in this class may be mentioned with praise the oxy-hydrogen light of Drummond, and the Bude light by Gurney. Latterly the catoptric and dioptric system of Fresnel, which consists in an ingenious and scientific construction of the lenses, and an adaptation of the compound Argand burners to suit them, has been introduced into several of our lighthouses with advantage,

but further experience is necessary to decide which is the best, the system of Fresnel above mentioned, or the old Argand system with the parabolic polished silver reflectors; both plans have been well executed by Wilkins and by Deville.

In the construction of Lighthouses since Smeaton much has been done, the one on the Eddystone by him serving in many cases as a model; that however on the Bill Rock by Rennie (1811) is remarkable, and differs from that on the Eddystone in its improved exterior form, the mode of making the floors, by which the lateral thrust on the walls is avoided, the dovetailing, and other details. Messrs. Stevensons, Walker and Halpen have also constructed several good examples, and recently Gordon's cast-iron lighthouses appear to merit attention for certain situations.

ROADS.

In proportion as the wealth and commerce of the country increased in the latter half of the last century, so it became absolutely necessary to improve the communication by roads and wheel-carriages, between all the different towns and districts of the empire, for supplying them with provisions, fuel, and the necessaries and luxuries of life, with greater facility and economy, as well as for expediting commercial intercourse; in fact, the one followed as the necessary consequence of the other, and the public seeing and feeling the beneficial effects of what had been effected, and convinced of the practicability and advantage of proceeding further in the cause of improvement, would not rest satisfied until those improvements were made; accordingly the improvements of roads attracted general attention. Originally, roads were mere footpaths, or horse tracks across the country, in the most convenient and shortest direction between the desired places, but wholly unadapted for wheeled carriages; by degrees they became practicable for the rude carriages of the times, and they were maintained in a very defective state by local taxes on the counties or parishes in which they were situated, nevertheless, nothing in the way of effectual improvement was attempted, until turnpike trusts were established by law, for raising or levying tolls or taxes from persons travelling upon the roads. Several Acts of Parliament for these trusts were passed previous to 1765, but in the early part of the reign of George III. many more were passed, notwithstanding violent opposition was made to the tolls. They subsequently became general, and penalties were recoverable at common law, against the trustees, for not keeping the roads in proper repair; a long period, however, elapsed before any good system of road-making was established. The old crooked horse tracks were

generally followed, with a few deviations to render them easy: the deep ruts were filled with any materials which could be obtained nearest at hand, and were thrown upon them in irregular masses, and roughly spread to make them passable: the best of these roads would in our time be declared intolerable. Road-making as a profession was unknown, and scarcely dreamt of, and the parties employed to make and keep the roads in repair were ignorant and incompetent to do their duties; but inasmuch as travelling was uncommon, and the funds at the command of the trustees were scanty, we cannot be much surprised at it, as they could not command higher talent. Engineers, except in cases of great difficulty, such as making a bridge over a deep and rapid river, cutting through a hill, or embanking across a valley, where more than ordinary skill was required, considered road-making beneath their consideration, and it was even thought singular that Smeaton should have condescended to make a road across the valley of the Trent, between Markham and Newark, in 1768. The great activity and prosperity, however, which resulted from the modern manufacturing system, convinced people of the value of time, and that easier and more rapid means of communication than the old roads permitted were required; hence the acclivities were partially reduced by cutting down the hills and raising the intervening valleys: improved bridges were built with easier ascents, and in some cases cuts were made to shorten the distance; still, however, the general line of the old road was preserved. The roads were certainly improved by this means, but still there was no general system; they were parcelled out into small districts under separate trustees, without any common concert or harmony in working together, and but little effectual progress was made. The importance of forming good roads was but imperfectly understood, the legislation connected with it was equally short-sighted, and many of the improvements in cutting down hills and leveling valleys were frequently repeated, from want of proper skill and foresight at first. The rebellions in Scotland, in 1715 and 1745, induced the Government of that day to turn their attention to the subject, and several roads were constructed by military engineers for military purposes.

Telford, previous to his being employed to construct the Caledonian Canal, had turned his attention to road-making, and was appointed by the Government to lay out new lines of road, both for the purpose of employing the then poor and thinly-scattered population of the Highlands, as well as to improve the districts by more general intercourse with the rest of the kingdom; he evinced a skill and knowledge which had not hitherto been bestowed on this important subject, but which was afterwards developed upon a greater scale in Ireland, and lastly in England, in his great works, the Holyhead, Liverpool, and Great North

Roads, formed in consequence of the increased communication with Ireland after the Union, and which were excellent models for roads throughout the Kingdom. Telford set out the roads according to the wants of the district through which they were made, as well as with a view to more distant communication, and the acclivities were so laid out, that horses could work with the greatest effect for drawing carriages at rapid rates. The road was formed by a substratum of large stones, with sufficient interstices between them for drainage; the materials laid on this foundation were hard and angular, broken into small pieces, decreasing in size towards the top, until they formed a fine hard surface, whereon the carriage-wheels could run with as little resistance as possible The transverse section of the road had no greater convexity or rise than was sufficient to cause the water to run readily into the side-drainage channels: by this means, the carriages not being inclined laterally, the weight was more equally divided on the wheels, whereby they moved more easily and with the least wear and tear of the roads. The surface of the road was always kept even and clean, by the addition of proper fresh materials where necessary, and distributed equally in thin layers immediately after rain, in order that the new materials might bind and incorporate properly with the old. Telford's system was afterwards extended by his assistant, Macneill, and is fully described by our late honorary member, Sir Henry Parnell, afterwards Lord Congleton, who, by his perseverance and support of Telford, mainly contributed to its extension and success. About the year 1816, M'Adam introduced his system, and brought it into general use in the vicinity of Bristol. It resembled in some respects that of Telford, but differing from it by making no foundation in the first instance; it consisted in simply laying a stratum of flints, or other hard materials, 10 or 11 inches thick, broken equally into small pieces about 2 inches diameter, and spread equally over the intended road; this soon became so consolidated together by carriages passing over it, that they could travel with great facility and expedition. The section and the mode of applying fresh materials and keeping it clean, resembled that of Telford. M'Adam, professing to be a road-maker only, devoted his whole time and attention to the propagation of his system, which was greatly superior to the old, and became very generally adopted. Its introduction and extension were in a great degree due to our honorary member, the Earl of Lonsdale, who is ever alive to improvement; and to his Lordship's exertions we are indebted for the present system of metropolitan roads, which has proved of great advantage to the public.

The great improvement in roads, which was accompanied by a corresponding improvement in the carriages and breed of horses, produced an extent of tra-

velling commensurate with the increased facilities afforded. Coaches were first introduced into England in 1580, during the reign of Elizabeth. Public, or hackney-coaches, were only established in London in 1625; and stage or public travelling coaches, not until a much later period: in fact there were few roads upon which they could pass; and for fear of being robbed by highwaymen, or of being overturned or stuck fast in the mire, and other accidents of the road, they seldom or ever travelled during the night. In 1666 (the year of the Fire of London) a coach was established, which travelled between London and Oxford in two days; and another, called the Flying Coach, afterwards started to perform the journey in thirteen successive hours, or at the rate of 4 miles an hour, but only ran during the summer months. The journey between London and Edinburgh by stage coach, which was begun in 1712, took thirteen days to perform the journey: in fact, so great was the difficulty and danger of travelling, that, before setting out upon a long journey, people made their wills, as if they never expected to reach their homes again. After the roads had become sufficiently improved, mail-coaches, upon an improved construction, to carry passengers and letters, were first introduced by Palmer in 1784, and the journey between London and Edinburgh was reduced to three days and nights by this conveyance. At the first appearance of this extraordinary novelty, the inhabitants of the rural districts crowded the roadside to see the royal vehicle, with its gaily-apparelled horses and scarlet liveried coachmen and guards, galloping by at the accelerated speed of 7 or 8 miles an hour; but, when it was increased to 10 and 11 miles an hour, by further improvements in the roads, carriages, and axles, by Vidler, Collinge, and others, ameliorating the breed of horses, and shortening the stages, and the distance between London and Edinburgh was performed in 42 hours, it was considered that this could not be exceeded—and so far it was true; for animal strength and endurance had reached its utmost limits, and, if any improvement was to be obtained, it was requisite to obtain it from a different source. In the race of improvement, the stage coaches were not behind the mails; and we have only to mention the Brighton, Oxford, Cambridge, Southampton, Shrewsbury, and numerous other coaches, to prove that the system was carried to the highest degree of perfection of which it was capable*. In 1821 there were 24,581 miles of turnpike roads in England and Scotland, and 8000 miles in Ireland; and since that time they have much increased.

* The transport of goods was equally defective as to speed, and was comparatively as costly as that of passengers; at times goods were from four to five weeks, and seldom less than thirty-six hours in going from Liverpool to Manchester, at a cost of forty shillings per ton; whereas at present they are conveyed in three or four hours, for three shillings per ton.

PAVING.

When the turnpike-road system was introduced, the pavement of the metropolis was improved by the substitution of square blocks of granite, in place of the rounded boulders, or large irregular pebbles, which had been previously used. Blocks of granite of various dimensions, have, by way of experiment, been laid on concrete, with the joints grouted with lime and sand, in order to ensure the greatest stability amongst the blocks. M'Adam's system was introduced in some streets where the traffic was light, but it did not equal the granite paving. Wood blocks in different forms, hexagonal prisms, or cubes, or rhomboids, with the grain placed vertically, or nearly so, have been introduced for paving, the blocks being either connected by wooden pegs, or merely laid upon a bed of concrete. This system was borrowed from Russia, and patents have been taken out by Stead, in 1839, and many others, for different forms of the blocks; it has the advantage of diminished noise and friction, but its great defect is that of being dangerously slippery in particular states of damp weather, and it appears in consequence likely to be abandoned. Asphalte, a natural brittle, bituminous substance, found in volcanic districts, was introduced from France for foot pavements in 1836; it is brought to a semi-liquid state by heat, then mixed with sand and gravel, and spread over a bed of concrete, and when cold, forms a compact and durable pavement. Flags, or flat gritstone paving blocks, have been used in larger blocks, and better laid, so that paving has been much improved; the great difficulty, however, in keeping it in order in London and great towns, is occasioned by its being constantly broken up, to lay and repair the numerous gas and water-pipes; and it is desirable that separate tunnels or subways should be employed for receiving them, as was suggested by Williams and others a few years since.

RAILWAYS.

Whilst the turnpike road and coach system was rapidly advancing towards perfection, numerous active and inventive spirits, aspiring after better things, were busily employed in racking their brains to invent a mode of travelling, or locomotion, which should far exceed its predecessors; great difficulties however presented themselves—and amongst the agents which were thought of none appeared so well adapted for the object as steam, the success of which, in the

hands of Watt and others, had proved so triumphant, wherever it had been applied; but, in order to attain the wished-for velocity, a different kind of road was required to that which had hitherto been used: and at length the railway system was introduced.

Railways, formed with wooden rails, or parallel pieces of wood, with carriages having wooden wheels to run upon them, had been in use at Newcastle as far back as 1681, for the purpose of conveying coal down from the mines to shipping-places on the banks of the Tyne; Labelye, in 1743, described improved carriages, used by Allen in stone quarries at Bath, having wheels with flanges of cast-iron, adapted to run on wooden edge-rails, being an improvement upon those at Newcastle; afterwards the wooden rails were plated with iron, which made the carriages run more easily with a greater load; cast-iron rails, or plates, were brought into use for the first time by Reynolds of Colebrook Dale in 1767; and more completely by Curr at Sheffield, with waggons having cast-iron wheels without flanges, the rails being in the form of tram plates; and in 1769 Edgeworth introduced three or four waggons drawn in a train, by one horse. These iron tramways, laid upon stone blocks, with the carriages above described, having smooth-tired wheels without flanges, came into general use, for drawing coals, stone, and other minerals, from the mines and quarries underground, and at short distances from canals; but no lines of any great length were made for general traffic. The first line of any extent, it is believed, was that at Loughborough, by Jessop, in 1789; also between Cardiff and Merthyr Tydvil, the Act for which was obtained in 1794; this was followed by the Croydon and Surrey Railway between Wandsworth and Merstham, in 1804: for the periods, all these were considerable works of the kind. About this time railways were used by the contractors during the execution of great works, at the London, the East, the West India Docks, and other places, where the transport of vast masses of materials was required; when the works were completed, the rails or plates, which were made with side flanges to keep the wheels in their places, were generally sold, and were occasionally used for constructing short lines to canals and shipping-places. The only power applied to draw the waggons was that of horses. These railways were considered inferior to canals, and were seldom used, except when the traffic was chiefly descending, so that the empty waggons could return with facility. The application of steam power to the propulsion of carriages might, it would seem, have naturally commenced with carriages on the common roads; but so many difficulties intervened, that the attempt was not made until after it had been effected on railways. Dr. Robin-

son proposed it to Watt in 1769, and Darwin mentions it in 1796; but the application of Newcomen's or Watt's engines, for propelling carriages, could not be attempted with any probability of success, as they required copious and constant supplies of cold water for condensing the steam, which would have rendered the machine so cumbersome and unwieldy as to be unmanageable. Watt's practice was to condense the steam at a comparatively low temperature: for although he tried it in almost every state from high to low pressure, he ultimately, under all circumstances, preferred employing steam at about 3 lbs. above the pressure of the atmosphere. Amongst his earliest investigations he made a model of a high-pressure engine, which acted very well; and he described a high-pressure locomotive engine in his specification of 1784; but he considered steam at such a high pressure to be unsafe, and did not make any use of it. His assistant, Murdoch, afterwards made a working model of a locomotive engine which acted very well, but he did not pursue it further. Leupold had proposed a high-pressure engine in 1725; and one was made by Cugnot at Paris in 1770, for propelling a carriage; but it failed entirely, and was never used.

Trevithick and Vivian obtained a patent in 1802, for high-pressure engines, in one of which locomotion was to be produced by the adhesion of the wheels, propelled by the engine working on the road. They also proposed ribbed wheels with nails or bosses, for the purpose of enabling the engine to ascend steep places. In 1804 they made a locomotive engine, which travelled upon the Merthyr Tydvil Railway; it consisted of one high-pressure cylinder, with a fly-wheel, and four bearing-wheels, two of which were turned by the action of the piston, and produced a velocity of 5 miles an hour, drawing after it several waggons, containing a load of about 15 tons. This locomotive worked by adhesion alone. The experiment was not continued, because the weight of the engine, with its cast-iron boiler, was considered too great for the rails, and might have occasioned considerable damage to them, and if the weight of the engine had been reduced sufficiently, it would have been too light, and the wheels would have slipped upon the rails. Thus we see that the great principle of adhesion, for producing locomotion, was clearly understood at the outset, and was only abandoned in consequence of the cast-iron plate rails at that time in use being unfit for carrying it into effect. In addition to the objection on the score of the weight of Trevithick's locomotives, more serious opposition arose against them in consequence of one of them having exploded in 1803. This objection was made to all Trevithick's locomotive engines, although ultimately they came

into use. He had made an attempt to propel carriages on common roads by steam in 1806, and constructed a carriage worked by steam, which was exhibited publicly in the neighbourhood of Bethlehem Hospital. To that ingenious and able man the origin of the locomotive system may be said to be due. In 1811, Blenkinsop took out a patent for using rails, having teeth like a rack in them, into which wheels, having corresponding teeth, were worked by the engine, thus securing the engine against the chance of slipping. This was brought into use for conveying coals from the Middleton Colliery, near Leeds, which may be said to have been the first practical employment of locomotive engines; but the expense, friction, noise, and slowness of the motion, which scarcely exceeded 4 to 5 miles an hour, prevented it from being generally adopted. In 1813 Brunton took out a patent for producing locomotion by levers, worked by the engine, resembling a good deal the motion of a horse. This however failed, and a serious accident occurred by the explosion of the engine attached to it. Chapman followed, and patented an invention which produced locomotion by means of chains laid along the line of road, passing round the wheels of the locomotive, and thus travelled forward. In 1813 Blackett resumed Trevithick's original plan, and constructed an engine which worked by adhesion alone, upon the rails at the Wylam Colliery at Newcastle.

George Stephenson, in 1814, improved upon all the former locomotives, and took out patents in conjunction with George Dodd in 1815, and with Losh in 1816. The locomotive, in his hands, soon became sufficiently perfect to be brought into general use on railways, for drawing coal-waggons at a greater rate than could be performed by horses. The weight of the engine was sustained on the axles of the carriages, by means of small pistons working in cylinders, supplied with water from the boiler, which acted like so many springs. Two steam cylinders were employed, and all the four wheels were impelled by them; the engine was followed by a tender carrying water and fuel. Here was a grand epoch in the history of railways, which were destined at no very distant period to effect such a complete revolution in the whole system of international communication, and to realise such extraordinary results, as even the most sanguine minds never anticipated. James, who had examined the machines, published a letter in 1815, proposing railways as a general system for travelling. The general introduction, in 1816, of the cast-iron edge rails, and the flanged wheels, which are said to have been invented by W. Jessop, long before, on the Loughborough Railway, instead of the cast-iron tram-plates with which the earlier railways had been laid, was soon followed by the introduction of wrought-iron

rails, in long pieces, at first in plain rolled bars, and afterwards rolled with projections on their upper edges, in order to give breadth for the wheels to run upon, as well as to increase the strength of the rails and enable them to bear greater weights without yielding. This was the patent invention of Birkenshaw, who made them in 1820. The above were great improvements in the system, and by degrees, all the details were worked out more effectually at the different collieries near Newcastle, and in the North, until the locomotives were so far improved as to enable them to travel at the rate of seven to eight miles per hour, drawing considerable loads behind them. The Hetton and the Stockton and Darlington Railways, by Stephenson, which were opened about 1825, contained all the improvements made up to that time; and the last Act of Parliament of the latter line authorized the use of locomotive engines.

The Liverpool and Manchester Railway Company obtained their first Act in 1826, under the Messrs. Rennie, but the kind of tractive power to be employed was left open for future determination. The railway works, however, proceeded, and considerable progress was made before it was decided what power should be employed. The Company employed Messrs. Walker and Rastrick to investigate the different means employed in the North as tractive power on railways, and to report which, in their opinion, they considered best adapted for the railway; upon the whole, they reported in favour of using stationary engines to draw the waggons and carriages. Stephenson and Rennie were in favour of locomotive power. The directors took up the matter with considerable spirit, and offered a reward of five hundred guineas for the best locomotive engine. The competitors for this premium were, Stephenson, Braithwaite and Ericson, and Hackworth and Brandreth. The weight of the engines was restricted to 6 tons, including the water in the boiler, and the load was limited to three times that weight, to be conveyed at the rate of at least 10 miles an hour. A trial of the engines of three competitors was made on a portion of the Manchester and Liverpool Railway in 1829, and the extraordinary speed of between 20 and 30 miles an hour was realized by Stephenson's engine "Rocket." So long as the motion upon the rails was produced by the rack and pinion, the greatest velocity attained scarcely exceeded 4 or 5 miles an hour; this was only adapted for the transport of heavy goods, and the expense, except in few situations, precluded it from being extensively brought into use; but the principle of adhesion being established, and 7 and 8 miles an hour obtained, the success of this great invention became evident, and it was predicted that its adoption would become general. Still, however, doubt and prejudice prevailed with many, and amongst

them were some men of no ordinary ability and experience; and it was not until the triumphant success of the great experiment in 1829 that the most sceptical were convinced of the application of the system eventually becoming universal. The scientific world beheld with amazement this extraordinary result, the consequences of which could hardly be foreseen. Springing at once from a velocity of travelling of 10 miles, the greatest speed of coaches, to 25 miles an hour, so far exceeded even the most sanguine expectations of its promoters, that they saw no bounds to its extension.

Stephenson's engine for the competition was upon an improved plan; the boiler contained numerous small tubes, through which the flame, or rather heat, from the fire-box or furnace, was made to pass, thus exposing a greater surface of water for the heat to act upon, and increasing its powers of evaporation. Booth, the indefatigable secretary to the Company, has the credit of this great improvement, which is now universally adopted, not only in locomotive but also in marine boilers. The engine had two cylinders which impelled the wheels, and the waste steam from the cylinder was discharged through a small tube or blast-pipe into the chimney, with a vertical jet, thus increasing the draught of the fire, and enabling it to produce the required heat in the fire-box. This blast-pipe was a most simple, ingenious, and important invention, which has contributed very materially to the improvement and perfection of the locomotive. The merit of this is claimed by both Stephenson and Hackworth. The boiler and apparatus were supported on the frame by springs, in the same manner as in ordinary wheeled carriages, thus preventing the concussion to which the different parts would otherwise have been subject, and enabling the machine to work with greater effect. The "Novelty," by Braithwaite and Ericson, was also a very ingeniously contrived engine. The "Sans Pareil," by Hackworth, was an improvement upon previous engines, but did not fulfil the conditions required so well as that of Stephenson, to whom the premium was awarded. Looking back at the result of these experiments, and what has occurred since, it appears injudicious that the weight and size of the engines should have been thus limited; for inasmuch as the power of traction of a locomotive engine depends upon the force of adhesion, which could only be produced by weight, and its capability of generating steam by increased dimensions, by limiting these two elements the power of the engine was necessarily reduced. Upon reflection, however, we cannot be surprised, for nothing but experience could have pointed out beforehand the present extraordinary results.

The Manchester and Liverpool Railway was opened in September 1830 with

great ceremony by the Duke of Wellington, Sir Robert Peel, Mr. Huskisson, and an immense concourse of spectators; but unfortunately this great event in the mechanical, commercial and social world was clouded by the death of that great man, Huskisson, in consequence of a locomotive engine passing over him, thus becoming one of the first victims of that extraordinary invention, of which he entertained so high an opinion. The first engines for this line were made by Stephenson, after the plan of the "Rocket," but improved; and in other engines, made soon after, he introduced a better arrangement of the parts, giving a greater number of tubes to the boiler, and adapting cranked axles to work the wheels; the first of these was the "Planet," which afterwards served as a model for the locomotives on other railways. Great improvements have since been made; heavier engines, weighing from 18 to 30 tons, capable of evaporating 200 to 300 cubic feet of water per hour, instead of 60 cubic feet, as in the early engines, with tenders capable of carrying 1000 to 1500 gallons of water; straight axles, with outside cylinders, like those of the "Rocket," have been again introduced, in order to increase the power and to obviate the objections raised against the cranked axles, as to their liability to break; engines with six wheels instead of four are now generally approved, as being safer; and those with coupled wheels have been made to increase the adhesion on steep planes. Improvements in the slide valves and working gear have been made for using the steam expansively in the cylinders, and rendering the engines more manageable either for backward or forward movement. The increased size and power of the engines have enabled them to ascend planes of 1 in 37, as on the Gloucester and Birmingham Railway, drawing after them heavy loads at considerable velocities, which at the first introduction of the locomotive would have been impossible. On that line, at the Lickey incline, engines made in America were at first used.

The mode of making and laying the rails of the permanent way has also partaken of the improvements in the engines; the original rails of the Manchester and Liverpool line weighed only 30 lbs. per yard, of the form termed "fish-bellied," and for the most part were laid upon stone blocks, after the plan of the colliery railways, on which the speed rarely exceeded 2 to 5 miles per hour; but when it was increased to 20 or 30 miles per hour, greater strength was necessary. The concussion produced by such heavy engines and trains, weighing from 50 to 300 tons, travelling at the rate of 20 miles and upwards per hour, soon deranged the light rails, and the concussion produced by the stone blocks rendered the employment of some more elastic medium desirable. Accordingly, heavier rails, parallel in depth, with a rib at top and bottom, were adopted, after the form

suggested by the experiments of Professor Barlow, with as much weight as the art of rolling iron could give, until it reached 75 lbs. per yard; instead of stone blocks wooden sleepers have been preferred; heavier and improved chairs for supporting the rails, with side keys of hard compressed wood to keep them in their places and resist the concussion, have been adopted; in this latter department Ransome and May have introduced great changes; the sleepers have been steeped in preparations from the patents of Burnet, Kyan and Bethell, for the purpose of securing greater durability. A variety of plans for making the rails and laying the permanent way on improved methods, have been proposed and tried, such as the bridge or hollow rail screwed down to longitudinal sleepers, which again are screwed to transverse sleepers below them, as adopted on the Great Western Railway; the solid rail secured by screws to longitudinal sleepers alone, as adopted on the Greenwich and Croydon lines; the parallel rail fixed to transverse sleepers, as adopted on the Dublin and Drogheda line, and others; all of which require the test of experience before any correct opinion can be formed as to their respective merits. Rails of prepared wood, patented by Prosser, have been proposed for ensuring the adhesion of the wheels on steep inclines, but have not been much adopted.

Stone railways or trams, which have been in use in the streets of Milan for a long period with considerable advantage, were employed at the Dartmoor Railway, to bring down granite from Dartmouth to Plymouth, a distance of 20 miles; also one of 12 miles in length, for a similar purpose, from Haytor to Newton; and a more perfect example was completed by Walker between the West India Docks and London, on the Commercial Road, a distance of 2 miles, in 1826. The tramway is composed of blocks of granite, 4 to 5 feet long, 16 inches wide, and 12 inches deep, nicely squared, bedded and jointed, and laid in a bed of concrete; it has been found of considerable service in reducing the friction, and enabling horses to draw heavier loads with facility in ordinary cases.

In addition to the adoption of wooden sleepers, it has in some cases, where great speed is employed, been considered advisable to introduce a layer of India-rubber, or elastic felt, between the rail or chair and the sleeper, in order still further to reduce the concussion, and to render the motion more easy; for now that the extraordinary speeds of 40 to 50 miles per hour have been effected, and are daily employed on the Great Western and other railways, too much care cannot be taken in constructing the works of the railway, and particularly in laying the permanent way; and until this be done it is scarcely prudent to exceed the present high velocities.

Before leaving this subject, it may perhaps be necessary to make a few remarks upon the width of gauge. This important question comprehends so many elements, that the determination of it is involved in considerable difficulty, and experience alone can decide it satisfactorily. Stephenson, who has taken such a prominent part in the introduction and extension of the railway system, adopted the gauge of 4 feet 8½ inches. Messrs. Rennie proposed 5 feet for the Manchester and Liverpool Railway before it was commenced; this, contrary to their advice, was afterwards made 4 feet 8½ inches. Brunel proposed, and carried into effect, 7 feet on the Great Western. The Eastern Counties was originally laid at 5 feet ~~6 inches~~, and afterwards altered to 4 feet 8½ inches. The Dublin and Drogheda is 5 feet 3 inches; and the Ulster lines are laid at 5 feet 6 inches. Cubitt now proposes an uniform width of 6 feet throughout the kingdom; the object of all being to ensure the greatest perfection in the engines as to speed, power of traction, economy of working, and safety in transferring passengers and goods. Taken in the abstract, a broad gauge would appear to afford the means of making more powerful engines, which can draw greater loads with greater speed and safety than a narrower gauge; but then it involves a greater first outlay, and a commercial question arises, is this necessary, when already, upon the narrow gauge, a speed of 60 miles an hour has been obtained with a tolerable load? A greater velocity appears not to be advisable, until the mode of making the road has been improved, and in the mining and manufacturing districts, the narrow gauge is stated to be more convenient and less expensive. Uniformity of gauge, however, is generally admitted to be desirable, in order to avoid the delay, expense and inconvenience of a change of carriage for both passengers and goods, and it is to be regretted that a broader gauge had not been adopted on the Manchester and Liverpool Railway, which might have served as an example to all subsequent lines, and have prevented the difference of opinion which has since prevailed. The gauge of the Great Western is probably greater than is necessary; but as it has already been adopted to a considerable extent, and has certainly realised very extraordinary results, and as it is impossible to foresee what further improvements may result, so as to obviate any inconvenience arising from a break of gauge, it would seem not to be desirable to stop the progress of improvement by altering it now, when it may be the means of creating further improvements in itself, as well as in the narrow-gauge system, which might otherwise never be thought of.

In designing a system of Railways for a district, so many circumstances must be considered that it is difficult to lay down general rules. Each case will require

a different treatment, according to the physical and geological features of the country, and the nature, extent and position of the traffic, whether of passengers or goods, or whether the terminal or intermediate traffic is most important, in order that each may receive its due share of accommodation.

Where both can be included in the main Trunk Lines, without too great sacrifice of distance, it may be advisable to do so; if otherwise, the intermediate traffic must be accommodated by Branches. The curves should be easy and regular. The planes or gradients should be laid out to suit the country and the traffic, always taking care to make them as level as possible; and where steep planes must be adopted, they should be of short duration.

The works should be substantial and executed with the greatest care; they should be well-drained throughout, particularly the embankments and cuttings; and the former, if possible, should be made from the base upwards.

The traffic on the Manchester and Liverpool Railway far exceeded the most sanguine expectations; and the passenger traffic, which was scarcely reckoned upon as a source of revenue (goods alone being relied upon), increased to such a degree, that it soon superseded every other conveyance between Liverpool and Manchester, and produced a large additional revenue. Notwithstanding, however, its brilliant success, the great cost of the railway, and the remnants of old prejudices against innovation, combined to keep alive the doubts and fears as to the profits which might be expected from other railways, less favourably situated than between two such large manufacturing and commercial towns, depending so entirely upon each other. Hence the numerous projects which were first brought forward met with a great deal of opposition, and did not receive that encouragement which subsequent experience has proved them to be entitled to.

After much delay, several Acts of Parliament for new lines of railway were obtained, notwithstanding the most strenuous opposition of the existing interests of canals, roads, landowners, &c., which was only overcome at enormous costs. Amongst the first of these may be mentioned the London and Birmingham, the Grand Junction, the Great Western, Bristol and Exeter, Southampton, Brighton, Dover, Leeds, York, and others. The prejudices against them have now vanished, and the great speed, economy and convenience of railway travelling, compared with the old system, has produced a corresponding increase in the traffic, so that notwithstanding the large capital expended in making the railways, they have in most cases, when properly considered in the first instance, produced a corresponding adequate return, and in consequence the mania for new lines has exceeded all former precedent. 1901 miles have been already executed on the

narrow gauge, 274 on the broad gauge; 614 miles are in progress of construction, and projects for 20,687 miles were actually introduced into Parliament last session, representing a capital of £350,000,000. Of these projects, Acts of Parliament have been passed for 3573 miles, requiring a capital of £129,229,767.

In most parts of Europe railways have already been constructed, or are in progress, or in contemplation, after the plan of those executed in this country. The following names must be borne in mind as associated with the invention and propagation of the railway system,—Barlow, Barnes, Birkenshaw, Bidder, Blenkensop, Blackett, Booth, Brandreth, Braithwaite, Brunel, Buck, Buddle, Cubitt, Curr, Dodd, Ericson, Giles, Gooch, Gravatt, Hackworth, Hawkshaw, Hawksley, James, Jessop, Leather, Losh, Locke, Lambourt, M'Neil, Pambour, Rastrick, G. and J. Rennie, Reynolds, G. and R. Stephenson, Trevithick, Vignoles, Vivian, Watt, Walker, Wood, and many others.

STEAM-COACHES.

Great efforts have been made to perfect steam-coaches, so as to enable them to travel upon turnpike roads, but hitherto without much success. The idea was suggested by Robison to Watt, in 1759, and Watt patented it in 1784. Symington proposed it in 1786. Trevithick's patent of 1802 was the first high-pressure engine that was actually made, and patents for improvements upon it have been numerous. Bramah constructed a steam-coach in 1822 for Griffiths, which was not successful. Gordon tried one in 1824, and Gurney, who was more successful, constructed some with boilers, having very small tubes; he attained a speed of 10 miles an hour on good turnpike roads, and ascended the steepest hills near London; he went from London to Bath and back, in 1831, and his steam-carriages ran for four months between Cheltenham and Gloucester; but it was extremely difficult, and too expensive, to keep them in order. Hancock constructed several with boilers composed of thin metal chambers; they ran for some time, with apparent success; but there were so many difficulties that they did not get into use. Dance, Field, Hill, Macerone, Russell, Cayley, and others, also attempted it with varied success; but the system is inferior to that of railway travelling, and it is now generally given up as hopeless. It has been proposed to employ highly compressed air in place of steam for propelling locomotive engines, first by Medhurst, in 1799, and since by others, but without any trials being made beyond mere models.

FAST CANAL BOATS.

Attempts were made by Grahame, and others, to accelerate the passage-boats on canals ; the mode was extremely ingenious, and at one time was brought into use on the canals in Scotland, the north of England, and other places. The mode was as follows :—A beautifully constructed boat, whose length was about ten times as great as the breadth, and drawing very little water, was drawn by two horses, commencing at a trot, and soon increasing their pace to a gallop ; the boat once put in motion required very little effort to maintain its speed, which was 10 miles an hour, and formed a considerable improvement in canal navigation ; increased expedition was also given to the boats for goods, and general speed and economy of charges and improvement in management prevailed. All this, however, came too late ; for although it would have been readily acknowledged at an earlier period, and might perhaps, for a while, have retarded the railway system, yet when once the latter was established, its superiority became manifest, and its progress irresistible. The railway system also gave increased stimulus to improvement in steam-boats, which had been previously in use, and which I shall presently notice more at length.

Taken simply at the velocity of 2½ miles per hour, the resistance or friction offered to the tractive power by a given load is in favour of the canal ; but as this resistance increases with the velocity at a far greater ratio on the canal than on the railway, the advantage with increased velocity becomes decidedly in favour of the railway ; and inasmuch as the value of time in everything has become more important, so railways must necessarily increase in superiority ; besides, as in any case having a large profitable traffic in passengers, which a canal cannot have, the extra power for conveying goods is comparatively very little, so that the competition even in heavy goods, in many cases, is in favour of the railway also. Some canals are now being amalgamated with, or converted into railways, being unable to withstand the competition with the railway.

STATIONARY-ENGINE SYSTEM.

Of the numerous other systems or projects, in addition to locomotive engines and horses, which have been suggested for propelling carriages along railways, two only worth mentioning have been brought into operation, viz. traction by ropes wound round drums or cylinders, worked by stationary or fixed steam-engines, and the more recently introduced atmospheric system. Traction by

ropes up steep planes had long been in use at the collieries in the North, where what are termed self-acting planes were established, upon which the descending loaded waggons attached to a rope, passing round a pulley-wheel, drew up by their superior gravity the empty waggons attached to the other end of the rope. The same principle was applied by Reynolds to transfer canal-boats from one level to another, in the case of the Ketley Planes, on the Shropshire Canals, in 1788, also in the subterranean portion of the Bridgewater Canal at Worsley, in 1797, and at other places. The system of rope-traction by stationary engines was adopted in the collieries of the North, the steep undulating nature of the country being well-adapted for it; Thompson applied the reciprocating system with great success to the Seaham and Durham Junction, and other railways, the lines being a series of successive planes, extending over 8 or 10 miles, without interruption, having fixed engines with ropes actuated by them, so that the traffic was transferred from one plane to another, taking advantage of gravity in the descents. The rope and stationary-engine system was applied to work the steep planes on locomotive railways, which were considered at the time too steep for the locomotives to travel upon, but recently locomotives have been so much improved, and rendered so much more powerful, that they can ascend planes at considerable velocities and with tolerable loads, where formerly it was considered impracticable. Examples of these may be mentioned;—the inclined planes of Edge Hill, and Rainhill on the Manchester and Liverpool Railway, the Lickey plane on the Gloucester and Birmingham, the Euston Square incline plane on the Birmingham Railway, and other places. The most remarkable and successful application of the rope system is the Blackwall Railway, by Stephenson and Bidder, in 1840. The line commences at Fenchurch Street, and terminates at the East India Docks, Blackwall, being about 3½ miles long; it is carried upon brick arches above the streets, and at each end, or terminus, there are powerful fixed steam-engines, turning large drums or cylinders, round which the ropes for drawing the carriages are wound at the rate of 25 miles an hour. Each pair of engines at the London terminus, built by Maudslays, is 224 H.P., whilst each pair at the Blackwall end, built by Barnes, is only 140 H.P., the line descending all the way to Blackwall. The plan of accommodating the intermediate traffic is very simple and ingenious; it is effected by attaching the carriages to the rope, by a clutch worked by a lever; this is readily detached by a man on the carriage, whilst the rope is in motion, and answers perfectly. The planes between Fenchurch Street and the Minories are worked by the momentum of the carriages one way, and by gravity the other. This system has its advantages

and disadvantages, and is more particularly applicable when the load is regular and constant, so that the full power of the engine may be employed to advantage. The wear and tear of the ropes is very expensive, but has latterly been much diminished, by the substitution of wire ropes for those of hemp. Connected with the Colliery Railways, the ingenious machines called Coal-drops, by Chapman and others, for lowering coals into ships without breaking them, must not be forgotten.

ATMOSPHERIC RAILWAYS.

The atmospheric system has been the subject of much discussion here and elsewhere. It was first proposed in 1824, by Vallance, of Brighton, where a working model was constructed of sufficient dimensions for the carriages to be introduced at one end of a tunnel, and the air being exhausted by a steam-engine at the other, they were propelled forward by the pressure of the atmosphere. It was even proposed to adopt the system for the speedy transmission of letters; the system, however, was necessarily so imperfect, that except for the ingenuity of the idea, it was of no practical utility. It was afterwards improved by Medhurst, in 1827, and was brought forward by Pinkus, in a more complete form, in 1834, by making the carriages travel outside the tube; and in 1839 it was further improved and patented by Clegg; since that period it has been brought into operation by Clegg and Samuda, who tried an experiment upon a working scale, in 1840, for about a mile in length, at Wormwood Scrubbs. This experiment showed that a load of 6 tons could be propelled at a velocity of 30 miles an hour, with an atmospheric tube only 9 inches diameter, and induced the leading proprietors of the Dublin and Kingstown Railway to adopt it, for extending that line to Dalkey, a distance of about $1\frac{3}{4}$ mile, where the country was difficult, and not well adapted for locomotives. That extension was opened in the latter end of 1843, and has continued working ever since. The line is single; the rails, although rather lighter, are laid upon the ordinary plan, and in the centre between them there is a tube about 15 inches in diameter, having a slit or opening at the top, which is closed by an elastic valve; a piston, fitted to the foremost carriage of the train, is inserted into the tube, which is connected at the upper end with an air-pump, worked by a steam-engine, which exhausts the air from the tube, and the piston attached to the foremost carriage is then urged along the tube by the pressure of the atmosphere, and draws the train with a velocity in proportion to the perfection of the vacuum in the tube; as fast as the piston advances, the valve in the slit of the tube is opened, and is

closed again after the piston has passed, and is rendered tight and impervious to air by a composition of fatty matter placed in the groove into which the edge of the valve falls. The planes of this line are extremely steep, being in places 1 in 50, and the curves are very sharp. The highest vacuum obtained has been 26 inches, with a speed of 35 miles an hour. The train returns from Dalkey by gravity alone. For a first experiment, it has been tolerably successful. The system is being tried upon a larger scale upon the Croydon and the South Devon Railways; a portion of the former has been opened, and a speed of 60 miles an hour has been obtained, with a vacuum in the tube of 27 inches; and a train consisting of 10 carriages, weighing 50 tons, has been propelled 5 miles in $8\frac{1}{4}$ minutes, or at the rate of 35 miles an hour, the barometer indicating a vacuum 25 to 28 inches. The engines are 3 miles apart, and a power of 300 horses is employed for the whole distance. The tube is 15 inches in diameter, and the air-pump 6 feet 3 inches diameter; the steepest plane is 1 in 50. The South Devon line has not yet been tried.

Considering the recent introduction of this system, and the new contrivances required in all its details, much has been done; with further experience, it is not improbable but that much more will be effected. Pilbrow, in 1844, patented a modification of the system, which is ingenious, but has not yet been sufficiently tested by experience to prove its merit. Hallette proposed to improve the valve on the top of the atmospheric pipe, by means of two small inflated elastic tubes, fixed in grooves on each side of the opening on the top of the pipe, through which the rod attached to the piston should slide between the tubes, and which should close the orifice as the piston moved. This ingenious idea requires the test of experience.

STEAM NAVIGATION.

The extraordinary improvement in the mode of communication which has been effected by steam power and railways on land, had been preceded by equally surprising and important effects produced by the application of steam to sea and river navigation. The vast increase of personal intercourse between people of different nations separated by the ocean, which has resulted from this great discovery, and which is still augmenting, has operated more than any other invention on record (not even excepting printing, which has been greatly extended by steam) towards realizing what was once considered Utopian, the bringing of the various nations of the world together, and uniting mankind into one great family, working harmoniously together for their common good. The steam-

engine, in its various and numerous applications, may justly be styled the grand improver and civilizer of the age. It is a gigantic yet docile labourer, equally well-adapted for extracting fuel and other minerals from the bowels of the earth, as for performing all kinds of toilsome, complicated, or delicate operations, whether for forging the ponderous anchor and cable to preserve the gigantic vessel of war from shipwreck, or for weaving the most delicate web for a lady's garment. Its power can be increased to almost any extent, and it can be made to perform with a degree of celerity, economy, and skill, every operation which formerly could be executed by the human hand alone, and an almost infinite variety of others, which without it could never have been attempted. It may also be employed as a means of conveying merchandise, and travellers from one place to another, whether for business or pleasure, with a degree of certainty, expedition, convenience and economy, attainable by no other agent. The increase of commerce, national industry and wealth, as well as greater personal intercourse between nations, serves to dissipate prejudices, and to create reciprocal good feelings towards each other, and thus to promote peace; but if, unhappily, war should ensue, then by the increased facility afforded for attack and defence, steam would equally serve to shorten its duration by rendering the results more decisive, and making mankind less willing to embark in it.

The origin of the application of steam for propelling vessels is claimed by several individuals of different nations; but it is generally admitted that to Great Britain is due the merit of having introduced and established the successful practice of the present age. The application of wheels to propel boats, dates as far back as the Romans; in 1682, Prince Rupert's barge was propelled in a similar manner, and tug vessels, with wheels worked by horses, for towing vessels against wind and tide, were proposed. Papin proposed, in 1690, to propel boats by racks and pinions with pistons working in steam cylinders; Blasco de Garay, a Spaniard, is said to have made an experiment on propelling a vessel in the presence of the Emperor Charles V., at Barcelona, in 1543. The experiment is reported to have succeeded, and received the approbation of the emperor, who paid all the expenses. The invention, if it existed, died with the inventor, and nothing further was heard of it until after the introduction of steam navigation, when the statement was made in order to claim for Spain the merit of this great invention. Had this claim been brought forward earlier, and published to the world, it perhaps might have been allowed; but appearing at this time, it could have no influence, and must clearly be regarded as in no way interfering with the title of Great Britain to the discovery. Jonathan Hulls, in

1737, published a small pamphlet, wherein he gives a plate representing a boat with a wheel attached to the stern, driven by a steam-engine to propel the boat, and tugging behind her a vessel of war. This is clearly the first representation on record of a steam-boat. He took out a patent for the invention; but experienced so much opposition from prejudice, that he does not appear to have prosecuted it afterwards. Hulls proposed to apply Newcomen's engine for propelling the wheel, but as it was very difficult to produce rotatory motion with that kind of engine, that may have been one reason why it was abandoned. Savery proposed, in 1698, to apply manual power to the capstan of a ship, by the intervention of a wheel and pinion for turning paddle-wheels attached to the sides of the vessel; and, at a later period, Captain Burton proposed a similar plan. All idea, however, of bringing the invention to bear, appears to have been laid aside until 1765, when the mechanical and scientific world had again turned their attention towards the improvement of the steam-engine, and Dr. Robison of Edinburgh proposed to Watt to apply steam for propelling vessels on land and by sea. Watt, however, at that time had not made sufficient progress with his invention, to enable him to take up and work out the idea with sufficient prospect of success, as it is evident, that he could not have considered Newcomen's engine at all calculated for the purpose; Watt, therefore, confined his views to perfecting his engine, foreseeing, no doubt, that when once that end was accomplished, other important results would follow.

The subject of steam-boats still lay dormant for a time. In 1782 the Marquis de Jouffroi is said to have made a steam-boat, 140 feet long and 15 feet wide, which was tried on the Soane at Lyons, but it was not successful. About the year 1787, Watt had so far perfected his steam-engine, and rendered it capable of producing rotatory motion, as to enable it to turn mills: he had thus overcome one of the principal difficulties, and prepared the way for the introduction of the modern system of steam navigation; but although numerous attempts were made with imperfect engines for propelling vessels, even after Watt had obtained patents for his improved engines, yet it was not until after the expiration of his patent for the rotatory engine in 1800, that it was applied to steam-vessels.

About the year 1788, Fitch and Ramsey, of America, and Serrati, of Italy, appear to have tried some experiments, and thus they lay claim to the invention, but upon this point there is no accurate information. In the same year, Miller, of Dalswinton, constructed a double boat, 60 feet long, with two paddle-wheels in the centre, to be moved by manual labour, in order to race with another boat propelled by oars in the usual manner; it was tried upon the sea near Leith,

when Miller beat his competitor, and the effect of this experiment convinced him that power only was wanting to bring the invention to perfection. Taylor proposed to apply the steam-engine for this purpose, and he then applied to Symington, a practical engineer of the day (who had previously proposed some improvements in Newcomen's engine, and had made a model showing how it might be applied for the purpose of propelling carriages), in order to assist him in applying the steam-engine for working paddle-wheels. A steam-engine with two cylinders, 4 inches in diameter, each of about one-horse power, was accordingly made by Symington and Taylor, and was applied to drive the paddle-wheels in the centre of the double boat, employed for pleasure on Dalswinton Lake, in the middle of October 1788, when it attained a velocity of about 3 miles an hour. The success of this experiment was complete as far as it went, and established beyond doubt the merits of the discovery; it therefore induced the ingenious and persevering projectors to prosecute it further by making another vessel of the same dimensions as the former one, to be worked by an engine upon a larger scale: the engine was made at Carron, and was of a peculiar construction, in order to avoid infringement on Watt's patent; it had two atmospheric cylinders of 18 inches diameter, the pistons of which were connected with a lever acting alternately and by means of chains; pulley-wheels and ratchets turned two paddle-wheels, one being placed before the other, in the space between the two parts of the double boat; this machinery, it will be observed, was similar to Hulls' plan, improved, however, by having two cylinders. The boats and engines were completed, and the experiment was tried on the Forth and Clyde canal on the 26th December, 1789, and was still more successful than the first, having attained a velocity of 4 or 5 miles an hour. An account of this experiment was published in the Edinburgh newspapers of the day. The signal success of this second steam-boat rendered further experiments unnecessary, and it now only remained to bring it into practical operation. Messrs. Miller, Symington, and Taylor had proved to the world the merits of the discovery, and not wishing to incur further expense or trouble in combating the prejudices and opposition of mankind, which invariably obstruct the introduction and prosecution of every great invention, did not pursue the subject further, but left it to others to work out and develope the powers of their extraordinary invention, which was destined, at no distant period, to produce such a wonderful revolution in the social world. The engines and machinery were accordingly taken out, and deposited at the Carron Works, and the boat, which was only a pleasure-boat, and fit for no other purpose, was transferred back to the lake of Dalswinton, and

again applied to its original purpose. Mr. Miller returned to his agricultural pursuits; Taylor to his profession of a tutor; and Symington to his profession of a practical engineer.

In 1793, Ramsay made some experiments for propelling a vessel by forcing water out of the stern by a steam-engine; this does not appear to have answered.

In 1795, Earl Stanhope, well-known for his mechanical genius, tried an experiment for propelling a vessel by means of a propeller in the form of a duck's foot; and about the same time Smith fitted a boat with an atmospheric engine on the Sankey Canal; none of these experiments, amidst several others which were tried, appear to have been very successful; the great difficulty seems to have been in producing the rotatory motion by the steam-engine employed for the purpose, and it is singular that none of them tried Watt's engine, which had then become generally known, and Boulton and Watt themselves were too busy in making their engines for the numerous mills and waterworks then becoming daily more general, to turn their attention to fresh speculations, the issue of which was at that time doubtful, and which did not promise to be so lucrative.

In 1801, Lord Dundas, who took great interest in mechanical pursuits, employed Symington to construct a steam-boat; this was propelled by an engine on Watt's plan, having one cylinder placed horizontally, and the piston, with a stroke of 4 feet in length, was jointed at the extremity, and attached to a connecting rod, with a crank at one end, turning a paddle-wheel, placed in a well-hole at the stern of the vessel, which had two rudders, one on each side of the cavity in which the paddle-wheel was placed. This was the first practical working steam-vessel, with an engine on Watt's system, and was called the 'Charlotte Dundas;' it was employed for towing vessels on the Forth and Clyde canal, and answered its purpose completely; but the proprietors of the canal objected to its being continued, in consequence of the agitation of the water produced by the paddle-wheels, which they alleged would injure the banks of the canal. In 1802, Fulton, who had been some time in England, hearing of Symington's attempts, went to Scotland, visited him on board his boat, and requested to see it tried. Symington accordingly got up the steam, made several trips up and down the canal, and fully explained to Fulton every part of the boat, steam-engine, and apparatus. Fulton made notes of everything, observing at the same time, that the objection of injuring the banks of the canals and small rivers might apply in England, but that in America, where they were upon a much larger scale, this inconvenience could not be felt, and he thought the application of steam-boats in that country would be of immense public and

private advantage, and stated his intention of introducing them there. After this visit to Symington, Fulton proceeded to France, where he constructed his first steam-boat, and tried it on the Seine, at Paris, in 1803, and proceeded to America soon afterwards. It is rather singular, that Napoleon, who was then First Consul, and who usually was alive to all great improvements, and carried them through with a degree of energy and talent which overcame all opposition, should not have appreciated the merits of the steam-boat, and should have allowed such a fine opportunity of benefiting France to have slipped through his hands; but perhaps the same may be said of England, as being still more extraordinary, for the advantages of the steam-engine and machinery had then become universally acknowledged. Fulton, however, impressed with the importance of the invention, and being thoroughly convinced of its ultimate success, pursued it with unremitting perseverance and energy, and in 1805 he applied to Messrs Boulton and Watt to make a steam-engine for a boat which he was about to construct in America: this boat was accordingly built in 1807. Watt's steam-engine reached America in 1806. The vessel was named 'The Clermont,' from his friend Livingstone's residence; the wheels and machinery were on Symington's plan, propelled by Watt's engine; the boat was tried on the Hudson River, and only attained a speed of 5 miles per hour. This was the first steam-boat used in America, and Fulton and Livingstone then took out patents for introducing steam-boats in various places in America, and built several others, upon a larger scale, for carrying goods and passengers, employing Messrs. Boulton and Watt to make the steam-engines, which were sent from England, each succeeding engine being larger than its predecessor. Although it was generally known that the steam-boats had succeeded perfectly in America, and that their employment was daily increasing, yet little or no attention was paid to the subject in England. The idea of employing steam-boats on the ocean had never been conceived, and the objections raised to the agitation of the water by the paddle-wheels on the Forth and Clyde canal were considered so strong, that doubts were generally entertained as to the success of the system anywhere but in large rivers, such as those of America. In 1812, however, Henry Bell, of Glasgow, who was well acquainted with, and had deeply considered all that had been done by Symington, determined to try once more whether the invention could not be applied on the Clyde; he accordingly caused a small boat of 25 tons burthen to be built at Port Glasgow, by John Wood, who has since become so well known as a ship-builder; it was 40 feet long, with 10 feet beam, and in it was placed a steam-engine of 4 H.P., on the bell-

crank principle introduced by Watt; the boiler was placed on one side of the vessel and the engine on the other, with four paddle-wheels worked by the intervention of spur gear; the wheels consisted of detached arms, with paddles or floats at the end, which, however, did not answer, and the complete wheel, according to Symington's plan, was subsequently adopted. This boat, which was called the 'Comet,' began to ply for goods and passengers on the Clyde, between Glasgow and Helensburgh (Bell's native place), in January, 1812, and attained the speed of 5 miles an hour*. The 'Comet' succeeded so well, that Bell determined to build another vessel of larger dimensions and power. Numerous other parties, seeing the success which had attended Bell's exertions, determined to follow his example, and several other boats were built during the succeeding years of 1813 and 1814; they were, however, still very imperfect, until Cook, of Glasgow, in 1814, constructed the fourth vessel, the 'Glasgow,' with an engine of 16 H.P. The machinery of this vessel was so much more

* In the collection of the Institution of Civil Engineers is the following handbill:—

"STEAM PASSAGE BOAT, THE 'COMET,'

"BETWEEN GLASGOW, GREENOCK, AND HELENSBURGH, FOR PASSENGERS ONLY.

"The subscriber, having at much expense fitted up a handsome vessel to ply upon the river Clyde between Glasgow and Greenock—to sail by the power of wind, air and steam, he intends that the vessel shall leave the Broomielaw on Tuesdays, Thursdays, and Saturdays, about mid-day, or at such hour thereafter as may answer from the state of the tide; and to leave Greenock on Mondays, Wednesdays, and Fridays, in the morning, to suit the tide.

"The elegance, comfort, safety and speed of this vessel require only to be proved to meet the approbation of the public; and the proprietor is determined to do everything in his power to merit public encouragement.

"The terms are, for the present, fixed at 4*s*. for the best cabin, and 3*s*. the second; but beyond these rates, nothing is to be allowed to servants, or any other person employed about the vessel.

"The subscriber continues his establishment at Helensburgh Baths the same as for years past, and a vessel will be in readiness to convey passengers in the 'Comet' from Greenock to Helensburgh.

"Passengers by the 'Comet' will receive information of the hours of sailing, by applying at Mr. Housten's office, Broomielaw; or Mr. Thomas Blackney's, East Quay Head, Greenock.

"HENRY BELL."

"*Helensburgh Baths, August* 5, 1812*.

Mr. Bell presented this new method of navigation to the British Government at three different times, viz. in 1800, 1803, and 1813*, when, after all his exertions, it was thought to be of no utility to Government. After it was denied him in 1803, he thought it very hard that such a discovery should lie dormant; and, on that account, he sent a description of the method of applying steam in propelling vessels against wind and tide, to all the emperors and crowned heads in Europe, and also to America, which last government put it in practice in the year 1806.

* Thus in the original.

perfect and powerful than any which had been previously constructed, that it served as a model for many others; and from this period steam-boats for river navigation were completely established.

Many of the engines employed for the above-mentioned vessels were upon what was termed the bell-crank principle; from their simplicity and portability, standing upon an independent frame, with the condenser forming part of it, they were well-adapted for steam-boats, and were consequently generally used. The bell-crank levers, receiving the motion direct from the piston, communicated it by means of a connecting-rod and crank to the main shaft, turning the paddle-wheels on each side of the vessel; the engine was placed on one side of the vessel and the boiler on the other. The boilers generally used were upon the principle proposed by Allen in 1730, and Smeaton in 1765, having an internal furnace and flue, surrounded by the water. This form of boiler was first brought into use by Trevithick in 1803 for high-pressure engines, and for low-pressure engines also in one of the earliest steam-dredging boats employed at Portsmouth Dockyard, under Bentham; but the exterior shell of this boiler was of wood, as proposed by Brindley in 1758; in steam-vessels the external shell of the boiler was made of wrought-iron. All the steam-vessels above-mentioned were worked by one engine only. In 1814 Boulton and Watt first applied two engines, connected together, for working a small boat on the Clyde.

In 1815, a small vessel, with a side-lever engine of 14 H.P. by Cook of Glasgow, made a voyage from Glasgow to Dublin, and round the Land's End to London; it then ran between London and Margate with passengers with considerable success, and this led to others being established in various places; the Scotch boat serving as a model.

In 1816 Maudslay made a pair of combined engines, each 14 H.P., applying the power to the paddle-wheel shaft by the crank instead of by cog-wheels, according to the previous mode.

In the same year, the late Mr. Baird constructed a steam-boat at St. Petersburgh with a boiler set in brickwork; this boat worked for some time on the Neva; a drawing of it exists in the archives of our Institution.

In 1817 Boulton and Watt purchased a small steam-boat called the 'Caledonia,' which had been built in the Clyde, with very defective engines. James Watt, jun., having constructed a new pair of combined engines on the side-lever principle, of 14 H.P. each, made a great number of experiments with the 'Caledonia,' and went with it to the Scheldt and other places; the arrangement of the engines, as improved by Watt, served as a model for several other vessels.

In 1818 David Napier caused the 'Rob Roy,' of 90 tons burthen, to be built by Denny at Dunbarton, with an engine of 30 H.P., with which he successfully established a regular communication between Greenock and Belfast: this may be said to be the first time that a regular communication by steam-boats between two distant sea-ports was established, and it set the example to every other place. Boulton and Watt, after the success of the 'Caledonia,' made a great number of marine engines of increased power, and with various new improvements, such as introducing wrought-iron instead of cast-iron for several of the moving parts; and in 1821 a great step was made, by establishing steam-boats between London and Leith. Two of these vessels, the 'James Watt' and the 'Soho,' with engines of 120 H.P., by Boulton and Watt, were the largest which had been made, and answered very well.

In 1819 the 'Rob Roy' left the Belfast station, and was transferred to the English Channel, to run between Dover and Calais. About this time Napier built the 'Talbot' of 150 tons, with two engines of 30 H.P. each, which ran regularly between Dublin and Holyhead. In this year also the late Mr. Rennie, who had for some time previous watched the progress of this great invention with considerable interest, foreseeing that it would ultimately supersede all others, proposed to the Admiralty to use steam-vessels for towing vessels of war into and out of harbour against wind and tide; being perfectly satisfied, that if once it was introduced into the navy, it could not be long before steam-vessels of war would follow; great doubts, however, as to its success were entertained and expressed by many of the official subordinates. Lord Melville and Sir George Cockburn, however, overruled all objections, and, as a first experiment, they consented to allow the 'Hastings,' a 74 line-of-battle ship, to be towed from Woolwich by the 'Eclipse,' a Margate steam-boat of 60 H.P. The 'Eclipse,' however, proved too weak, and after towing the 'Hastings' a few miles, it returned, and the 'Hastings' went to Chatham with her sails alone; the experiment was thus not quite so successful as could have been desired; nevertheless Rennie still determined to persevere. Oliver Lang, the master-shipwright of Woolwich Dockyard, entered fully into Rennie's views, and warmly assisted by every means in his power the introduction of steam-vessels into the navy, contrary to the opinions of many of his superiors. At length the Admiralty, at their recommendation, ordered the 'Comet' to be built according to the draft and plan, and under the superintendence, of Mr. Lang; she was 115 feet long and 21 feet wide, drawing 9 feet of water, and a pair of engines of 40 H.P. each were ordered for her from Messrs. Boulton and Watt: this was the

first steam-vessel in the navy, and it is still in use. By degrees several other were built.

In 1820 a steam-tug was built by Manby for Messrs. Smith, for the purpose of towing their barges upon the Humber; and in the same year Maudslay and Field applied the expansive action of steam in the cylinder, which was a great improvement; also escape-valves for the water which might boil over into the cylinders. In that year also steam-packets were introduced on the post-office station between Holyhead and Howth; and the 'Britannia,' with oscillating-engines, and several other steam-packets, were built by Manby for the Dover and Calais station.

In 1825 the General Steam Navigation Company was established by William Jolliffe, who built two of the largest vessels which had yet been tried, called the 'George the Fourth' and the 'Duke of York;' they were between 500 and 600 tons burthen, and had engines of 130 H.P., furnished by Messrs. Jessop of the Butterley Iron Works: these two vessels were intended to establish a regular communication between London and Cadiz and London and St. Petersburg; they accordingly started in September 1827, and answered extremely well, notwithstanding the heavy storms which they encountered in the Bay of Biscay and in the Baltic. The General Steam Navigation Company, considering the ideas of Jolliffe too extended, parted with the two vessels (which were afterwards purchased by the Government), and limited their views to the British Channel and the German Ocean. About this period, the 'Enterprise,' of 500 tons burthen, which was built by Gordon, and had a pair of combined engines of 120 H.P. constructed by Maudslay and Field, made the voyage from London to Calcutta, by the Cape of Good Hope. The advantage and superiority of steam-vessels, in every respect, for both river and sea navigation having been now thoroughly established, their employment became universal; and the size, power and number of the vessels increased daily in every part of the empire.

From this period nothing remarkable appears to have occurred, until the construction of the 'United Kingdom,' which was by far the largest in size and the most powerful that had been made. She was 160 feet long, 26½ feet beam, and 200 H.P.; the vessel was built by Steele, of Greenock, and the engines by David Napier. As deep-sea navigation by steam advanced, it became an object of considerable importance to save fuel, and to obviate the inconvenience of the incrustation of the boilers by the deposit of salt, and other sediments occasioned by the use of sea water; David Napier therefore introduced the system of surface condensation, the condenser being made of a series of small copper tubes,

through which the steam, after being used, passed from the cylinder to the air-pumps, the pipes being surrounded by a constant supply of cold water, so that the steam was condensed and the water was returned directly back into the boiler, to be again converted into steam, without the admixture of salt water according to the usual plan, thus employing the same fresh water over again, whereby the above-mentioned inconvenience of incrustation of the boilers was in a great measure avoided. Hall afterwards tried the same system with certain modifications, and it was employed in several vessels; but like Watt, Cartwright, and others who had tried it, he found the condensation was not so complete, and the weight and cost, and the difficulty of keeping the apparatus in order, have hitherto prevented it from being generally used; for although it possesses advantages in many respects, still upon the whole they do not counterbalance the disadvantages, and the old system of condensation by jet, with the aid of the brine pumps, is more generally employed. The brine pumps and refrigerators were invented and patented by Maudslay and Field in 1825, and were used on board the 'Enterprise*.' After the 'United Kingdom,' numerous vessels of similar and even greater size were constructed, to ply between London and Leith, Glasgow and Liverpool, and elsewhere.

The next great step in advance was the crossing the Atlantic. This had long been in agitation, and was freely discussed by numerous enterprising minds, anxiously bent upon working out the fulfilment of such a desirable and important object; but the great practical difficulties involved in the execution were not so easily overcome.

To construct a vessel of sufficient size, with engines of adequate power to propel her through the storms of the Atlantic, and carrying with her sufficient fuel to keep the engines in motion, was considered by many (and among them were very competent authorities) to be extremely doubtful, but by the world in general the task was considered to be wholly impracticable. To Bristol is due the origin of this great undertaking, and a Company of enterprising individuals, with Brunel as their consulting engineer, was formed for that object; it was, however, with difficulty that they found engineers to carry it into effect, some of the first constructors of the day having declined to undertake it. Messrs. Maudslay and Field, however, who had already taken such a prominent part in the prosecution of steam navigation, saw their way, and boldly engaged to construct engines of the requisite power, well-adapted for the purpose. Accord-

* Various processes for preventing the incrustation of boilers have been tried, but blowing off at stated intervals appears amongst the most simple and *efficacious* remedies.

ingly, a vessel, called the "Great Western," was designed by Paterson, and built by him at Bristol; and the engines were completed and fitted on board in March, 1838. The vessel was 210 feet long, and 38 feet beam, drawing 15 feet when laden, being 1240 tons burthen, and capable of carrying 500 tons of coals, which it was calculated would last twelve days. The engines were upon the side-lever principle, each of 210 H.P., with cylinders 73 inches diameter and 7 feet stroke, making 15 strokes per minute; they were fitted in cast-iron frames, with the latest improvements. The boilers were constructed with the flues over the fires; they were called double-story boilers, and have been since much used; they had brine pumps, and were worked under a pressure of 5 lbs. per square inch; the total weight of the engines and boilers, including the water and the paddle-wheels, was about 420 tons. The vessel was completed with her engines, and made her first trial on the Thames in March, 1838, realizing 12 miles per hour. On Sunday, 8th April, she started on her first voyage from Bristol, under the command of Captain Hosken, with seven passengers, and a cargo of 50 tons of goods, besides 500 tons of coals, and reached New York on Monday, 23rd April, a distance of 3000 miles, in thirteen days and ten hours. Her arrival created the greatest interest; the quays were crowded with spectators, anxiously waiting to give a hearty welcome to the enterprising and successful adventurers, who had thus so triumphantly solved the grand problem, and had brought the New World within a few days' sail of the Old. On her return she left New York on the 7th May and reached Bristol on the 23rd, with 70 passengers; performing the voyage in fifteen days. The success of this voyage across the Atlantic having exceeded the most sanguine expectations of its promoters, and indeed of the whole world, there seemed no bounds to the extension of steam navigation; other companies were projected and numerous larger and more powerful vessels were designed, in equal confidence of success; then followed the 'British Queen,' by Napier, of 500 H.P., the 'Liverpool,' of 500 H.P., and the 'President,' of 600 H.P., whose melancholy fate served for a time to damp the ardour of speculation. The practicability of steam communication across the Atlantic having thus been established, and its superiority over the old sailing system being clearly proved, time only was necessary to render it perfect. The line from Liverpool to Boston was then designed, and carried into effect by Cunard, for conveying the mails; it consisted of four fast vessels, the 'Acadia,' 'Caledonia,' 'Hibernia,' and 'Cambria,' of about 1000 tons and 450 H.P. each. This was followed by the gigantic project of the Royal Mail Company, for carrying the mails between England and the West Indies, consisting of twelve vessels, each of about 1200 to 1300 tons

burthen, and 420 H.P. The engines of these vessels resembled very much those of the 'Great Western,' whose complete success induced their being taken as models for others. The great weight and space occupied by these engines, being upon the average of about a ton for every horse-power, rendered it difficult for them to carry any great amount of cargo beyond the passengers, and thus the profits as a mercantile speculation were materially lessened; it became extremely desirable, therefore, to ascertain whether engines, equally efficient, could not be made of less weight, and to occupy considerably less space.

In order to effect this object, engines were invented, by which the power was applied directly from the piston to turn the paddle-wheel shaft, without the intervention of side levers; these were called direct-acting engines, and at first great objections were made to them in consequence, as was asserted, of the loss of power arising from the obliquity of the action of the piston-rod upon the crank on the paddle-wheel shaft. Messrs. Seawards were among the firstto introduce this system into the 'Gorgon,' and notwithstanding the objections above stated, it has been improved by them and by other engineers, and has materially gained ground. The obliquity of action of this system, compared with that of the side-lever system, can only be considered in the light of a little extra friction, which is fully, if not more than compensated for, by the reduction of weight and space. The modifications of the system by Miller and others have been very successful. Even the objection of extra friction, however, if tenable, is obviated by the vibrating cylinders, described in Trevithick and Vivian's patent in 1802; patented by Witty in 1813, and by Manby in 1821, by whom the first engines of the kind were constructed; subsequently improved by Maudslay and Field, and now extensively manufactured by Penn, Miller, and others; Maudslay and Field's double cylinder engines, so arranged that a long connecting rod is obtained by its being enabled to descend between the cylinders; the Trunk engine by Humphrys; and the modification of the concentric cylinders by Joseph Maudslay; as well as other varieties of this system by different makers. The substitution of wrought-iron for cast in a large portion of the frame and condensers; the tubular instead of the common flue boiler, first proposed by Blakey in 1764, and afterwards improved in the locomotive boiler, and introduced into steam-vessels by Maudslay and others about the year 1829, as well as the use of steam of higher temperature and increased expansive action, have combined materially to increase the effect of the engines, and reduce the consumption of fuel; so that the space and weight occupied by them is now reduced to nearly one-half what it was originally, or in other words, engines of double

the power now only occupy the same space and tonnage in the vessel; thus a material advantage has been gained in enabling vessels to carry a larger quantity of fuel, by which they can extend their voyage; and greater power is rendered disposable for propelling the vessel through the water. As economy of time becomes daily more important, every means which can effect it are brought into operation, and thus the power of the engines has been continually augmented, in order to produce greater speed and shorten the duration of the voyages. Referring to the navy, we find, that in 1822, 80 H.P. was the largest; in 1827, 160 H.P.; in 1828, 200 H.P.; in 1830, 220 H.P.; in 1838, 440 H.P.; and in 1845 we have the 'Retribution' and 'Terrible,' with nearly 1000 H.P. in each, and it is not improbable that, ere long, greater power will be employed*. Whilst the royal steam navy has been making such rapid progress, the mercantile steam navy has not only kept pace with it, but has even led the way; for the enterprising, commercial spirit of this country is ever on the alert; every improvement is seized upon with avidity, and the greatest inducements are held out to make new discoveries; in fact, nothing but constant progress can satisfy the restless spirit of improvement. In the infancy of the art, we were satisfied with 5 or 6 miles per hour; now, when we have attained above 17 miles per hour, we are confidently looking to a still greater result.

Whilst the improvements, above-described, have been making in the engines and in the mode of applying them, various attempts have been made to obviate the inconvenience and loss of power occasioned by the concussion of the floats of the ordinary paddle-wheel entering the water, as well as the heavy drag or back action of the water when the floats leave it; numerous experiments and inventions have been tried for constructing a wheel, of such a form that the floats shall always enter the water in the most advantageous manner, and having effected the object, shall leave it again with the least resistance. To describe the numerous inventions of this kind would be foreign to my purpose, and would occupy too much of your time; it will suffice to mention that of Buchanan, by which the floats always enter and depart from the water perpendicularly; those of Cavé, Oldham, Morgan, Perkins and Barnes, which are modifications of it, differing chiefly in the angle at which the floats enter and leave the water, and the mechanism attached to the wheel by which the motion is communicated to the float-boards; the principle of this invention is extremely good, but in practice it has unfortunately been found, that the wheels of this construction, after a little use, are liable to get out of order; it is not therefore generally

* The total amount of steam-power employed in the Royal Navy is about 35,000 H.P.

adopted, although, whilst they are in order, considerable advantage is doubtless gained. To obviate this inconvenience, as well as that of the common wheel, Field invented what is technically termed the Cycloidal Wheel; this consists in dividing each float board into several parts or narrower boards, and arranging them so nearly in cycloidal curves, that they shall all enter the water at the same place in immediate succession; as the acting force of each board is radiating, it propels whilst passing under the water in the ordinary way, and when it emerges, the water escapes simultaneously from each narrow board; this principle was not followed up by its inventor, and was afterwards patented by Galloway, since which it has been very generally adopted. The principle of reefing the paddle-wheels is also used, so that when the vessel is deeply immersed, the leverage of the paddles can be shortened, and when light, it can be lengthened, and can thus be always adjusted to the power of the engines.

As economy of fuel is an object of the greatest importance, so in long voyages it is advisable to employ the wind as a moving power, as much as possible, when favourable: it became therefore desirable to contrive a simple means of detaching the paddle-wheels from the engines, so as to allow them to turn round with the motion of the vessel through the water, and thus to prevent them from impeding her way; various contrivances of this kind have been invented, but one of the most simple, and which is now much employed, was invented by Braithwaite and Milner; it consists of a friction clutch attached to the paddle-shaft, which by means of keys and screws can be tightened or slackened with facility, and thus the paddle-wheel is attached or released at pleasure. Numerous attempts have been made to introduce the rotative engine without pistons, but they have hitherto not been successful.

The great results rendered by steam navigation induced the mechanical world to turn their attention towards the extension and improvement of it; Boulton and Watt, Maudslay, Field, Robert and David Napier, Jessop, Glynn, Barnes, Miller, Ravenhill, Girdwood, Manby, Scott, Sinclair, Caird, Todd, Fawcett, Bury, Forester, Seaward, Penn, Fairbairn, Hall, Rennie, and numerous other able men, devoted their minds to it, and have produced some splendid examples of engines and mechanism in that department. When we look back to Symington's original engine, in 1788, it appears to have been so changed as scarcely to be recognisable as the same; and from a speed of 5 to 6 miles an hour in smooth water, we now find that a speed of 8 and 9 miles an hour against a heavy gale and head wind in the Atlantic, and above 17 miles in still water, has been obtained, whilst improvements are in progress which lead us to anticipate, at no

very distant period, far greater results; much of this, no doubt, is due to the perfection of the workmanship, as well as to the more correct proportions and adaptation of the various parts of the machinery, compared with what was formerly done, and which it was impossible to accomplish with the slender and inefficient means then at command; for this we are greatly indebted to the improved self-acting tools of Whitworth, Fox, Lewis, Sharpe, Roberts, Nasmyth, and others. The improvements in the form and construction of the vessels have also contributed much: and in the investigation of this difficult subject we are much indebted to John Wood, Oliver Lang, Fearnall, Fincham, Ditchburn, Symonds, Rule, Seppings, Scott Russell, Edye, Patterson, White, Pasco, and others.

IRON VESSELS.

Neither must we forget the very important improvement in the introduction of iron for the construction of vessels, which enables us to combine lightness and elegance of form with strength and durability. For this valuable addition to marine architecture we are indebted to Aaron Manby. In 1820–21 he constructed at Horseley, near Birmingham, a wrought-iron boat, called the "Aaron Manby," 120 feet long and 18 feet beam, and when laden drawing 3 feet 6 inches water; it was propelled by Oldham's feathering paddle-wheels, worked by a single engine of 80 H.P., and was built for the purpose of plying on the river Seine. The boat was completed in 1821–22, and was navigated across the Channel by the present Sir Charles Napier, who was deeply interested in the undertaking; it was not only the first iron vessel that ever made a sea voyage, but also the first that conveyed a cargo from London to Paris direct, without transhipment. She continued plying between Paris and Havre for several years, until superseded by other more powerful and improved boats. The hull is yet in existence, and is still used with new engines on board, as are three others which were built about the same time. In 1832 Maudslay and Field built four iron vessels for the East India Company, for the navigation of the Ganges, and fitted them with oscillating engines, of the united power of 60 horses; they were 120 feet long, 24 feet beam, and drew 2 feet water; they were so successful that six more were ordered shortly afterwards. The use of iron, however, did not make much progress until recently, on account of the prejudices and obstacles which generally, if not invariably, impede the progress of all great inventions. At present iron is much employed for vessels, and promises in many cases to supersede timber. Objections against its general employment have been urged, on

account of the bottoms of the vessels being liable to become foul on long voyages; and for the purposes of war, the splinters of the iron when struck by shot are said from recent experiments to be more detrimental than from wood. The art of building iron vessels is however in its infancy, and it is very probable that further experience and investigation will in a great measure obviate the evils. The strength, lightness, and other qualities that have been mentioned, give it great advantages for the construction of fast-sailing passage-vessels, and the water-tight bulk-heads constructed with it give great additional security in case of accidents; these water-tight bulk-heads are now almost universally adopted; but the precise date and origin of their introduction are not very clear. Captain Evans, of Holyhead, proposed them for timber vessels in the year 1826, and soon after that time they were used in an iron vessel constructed by Grantham for C. W. Williams. Examples of their importance have frequently occurred, demonstrating the necessity of their introduction into all vessels, whether for river or sea navigation.

SCREW-PROPELLING.

Great as has been the result of steam-navigation under the paddle-wheel system, still as perfection is approaching, it cannot be denied that it has several disadvantages when applied to sea navigation during stormy weather, which it is most desirable to obviate. Paddle-wheels act to the greatest advantage in smooth water and upon an even keel. The unequal immersion of the paddle-wheels during the rolling of the vessel, in a heavy sea, prevents that uniformity in the action of the engines which is necessary to ensure their greatest effect, and although this may be lessened, to a certain degree, by the use of mechanical or feathering wheels, as I have already stated, the complexity of their construction is objectionable. The resistance, offered by the paddle-boxes to the wind, in addition to their top weight, has a sensible influence in diminishing the speed and effect of the engines, and in ships of war, the great space occupied by the wheels on the broadsides of the vessels, materially interferes with the efficiency of the batteries; moreover, the wheel, as the principal propelling agent, being constantly exposed to shot, is under very considerable risk of having its efficiency impaired. The idea, therefore, of substituting for it some other propelling agent had long been a favourite object of investigation amongst engineers. The origin of this, like every other great invention, is very difficult to be ascertained with accuracy, as the same idea not unfrequently occurs at the same time to different individuals, totally unconnected with each other. The first idea of

stern-propelling was very probably suggested by the movement of fishes, whose chief propelling power exists in the tail, as also from the common and ancient practice of sculling a boat from the stern. A rude idea of stern-propelling is attributed to Duguet in 1727, but it was so totally different from the system now employed, that it can scarcely be called the same invention. His system consisted of two boats, connected together by two cross beams with a screw, inserted between the boats; this double boat was moored to a post in the river, and the current, acting upon the screw, turned it round; this motion, thus generated, was communicated over pulleys, to which were attached the vessels to be drawn along: this plan may be likened to the effect of a water-wheel, or any other fixed first mover; still there is an idea of the screw, which, if pursued, might have been converted into screw-propelling. In 1768 Painton proposed the pteraphore to be applied to the bow and stern and sides of a vessel horizontally, but does not describe how it was to be moved. Lyttelton also proposed a screw-propeller in 1794. The first practical experiment, however, appears to have been made by Shorter in 1802, with a propeller like the sails of a windmill, applied to the stern of a vessel in the Thames. He afterwards tried several propellers, particularly in the 'Superb' line-of-battle ship in Gibraltar Bay, worked by a screw by the intervention of the capstans, by which the vessel was moved through the water at the rate of about 2 miles an hour.

Shorter does not describe the kind of propeller used in this experiment, although Napier, who afterwards proposed a similar plan without knowing what had been done, when he accidentally found Shorter, had from him an account of his experiments, and saw a large collection of propellers applicable to the bow, stern, sides, and every part of the vessel: Napier acknowledged and admitted that Shorter had conceived almost every possible kind of arrangement, and that his models and plans comprised most of the systems since made public by different parties; Shorter also exhibited several experiments with different propellers, and attributed the best results to a propeller with a single blade projecting from the axis. In 1824 a work was published under the direction of the French government, describing the several modes of propelling in use in America, on the principle of the screw; one plan was to have a hollow in the bottom of the vessel nearly as long as the vessel itself, with a screw revolving in it to produce motion forwards or backwards; another form of this system was to have a double screw between two boats. In 1825 a Company was formed for applying Brown's gas-vacuum engine to navigating boats on canals, and a premium was offered for the best invention for propelling boats without paddle-wheels. In 1827 the in-

genious and indefatigable Tredgold, in his work on the steam-engine, described and investigated the theory of screw-propelling; about the same time, or perhaps rather before, Brown, the inventor of the gas-vacuum engine, proposed to apply a propeller, consisting of two blades placed at an angle of about 90° to each other and 45° to the axis; this was intended to be placed in the front of the bow of the vessel, and attached to a shaft working through a stuffing-box, which could be raised or lowered at pleasure. He obtained the premium of the Canal Towing Company for this, and they determined to pursue the subject further; in furtherance of this object, they built a vessel at Rochester with a gas-vacuum engine of 12-horse power, which was applied to working Brown's propeller by means of bevel gear; the result of this experiment does not exactly appear, although it was considered sufficiently satisfactory for Brown to continue his investigations: he accordingly built another boat with similar engine and machinery, and made several experiments with it on the Thames, near London, when he is said to have attained the velocity of 7 miles an hour with it. Subsequently, Cameron, Woodcroft, Lowe, Ericson, and others pursued the subject and took out patents for various modifications of screw-propelling; nothing, however, was materially effected until the year 1836, when T. P. Smith obtained a patent for the application of a screw to propel vessels, by placing it in that part of the stern of the vessel called the "dead wood." He accordingly built a small vessel, and made numerous experiments with her on the Thames; this little vessel was 34 feet long, 6 feet 6 inches beam, and drew 4 feet water; in it he placed a small high-pressure engine, with a cylinder 6 inches in diameter, and 15 inches stroke, which was applied to working a screw 2 feet diameter, having a pitch of 2 feet 5 inches. With this vessel he obtained a speed of from 7 to 8 miles an hour; he then tried her on the sea between Ramsgate and London, and she answered very well in driving against the wind in a heavy sea. Upon the success of this experiment, a Company, called the Ship-Propelling Company, was formed, Smith being their adviser, and under his directions a vessel, called the 'Archimedes,' of 232 tons burthen, was built in London by Whimshurst; she was 125 feet long and 21 feet 10 inches beam, having a draught of water of between 9 and 10 feet; she was propelled by a pair of engines of the united force of 80 H.P. The engines and machinery, which were made by Messrs. Rennie, instead of being placed transversely in the vessel, as was usual in paddle-wheel steam-boats, were placed longitudinally; these engines were upon the direct-acting principle, and their power was applied towork the shaft upon which the propeller was placed, by means of two spur-wheels with teeth of

hornbeam wood, and two pinions with iron teeth working into each other, the motion of the propeller shaft being 5·33 to 1; or, in other words, when the engine made 25 strokes, the propeller made 133·3 revolutions. The propeller, which was in the dead wood, was united to the shaft, by means of a water-tight stuffing-box passing through the stern of the vessel. The propeller at first consisted of a single-threaded screw; but this not answering so well, another screw was employed, with two threads opposite to each other, 5 feet 9 inches diameter, and 8 feet pitch. The 'Archimedes' obtained a velocity of 9 miles per hour through the water, and proved herself an admirable sea-boat, going head to wind in a heavy sea, and she established beyond all doubt the success of the invention, and its superiority over paddle-wheels in many cases; still, however, much remained to be done before prejudice could be overcome, and before the system could be brought to such perfection as to compete in velocity successfully with paddle-wheels, which had so long and so completely engrossed the public attention as scarcely to leave an opening for any other system; latterly, however, screw-propelling has made considerable progress. In 1842, the 'Bee' was constructed by Maudslay and Field for the Government; she was worked by a steam-engine of 10 H.P., adapted for driving either the screw or the paddle-wheel in the same vessel, and thus to try the comparative merits of the two systems. From the trials and experiments made with the 'Bee,' it appeared that upon the whole the paddle-wheels had an advantage as to speed under all circumstances. In 1840, the 'Dwarf,' of 210 tons burthen, which was the first screw vessel ever commissioned in the British navy, was constructed by Messrs. Rennie; the engines, of 120 H.P., upon the direct action principle, were attached to two spur-wheels, with two pinions for working the screw upon the propeller shaft, on the same plan as the 'Archimedes.' The 'Dwarf' proved herself an excellent sea-boat, and attained a speed of 12¼ miles per hour through still water. The 'Rattler' was the second screw-propelling vessel introduced into the navy. She was 176 feet long, and 32 feet 8 inches beam; drawing 11 feet 3 inches water, carrying 20 guns, and was about 888 tons burthen. The engines, of 200 H.P., were by Messrs. Maudslay and Field; and her screw, which was 10 feet diameter, and 11 feet pitch, was driven by cog-wheels; the screw made 103 revolutions per minute, being in the proportion of 4 to 1 of the speed of the engines; her velocity through still water was 9½ miles per hour, and she proved a good sea-boat. All these have been surpassed in speed by the Royal yacht, the 'Fairy,' built for Her Majesty by Ditchburn, with engines by Penn; she is 260 tons burthen, with two oscillating engines of the united force of 125 H.P., driving

one spur-wheel and one pinion; the screw consists of two blades, and makes 250 turns per minute, being in the proportion of 5 to 1 of the moving power. The speed of the 'Fairy' is $15\frac{3}{4}$ miles per hour through the water. The merits of the screw system have now been so completely tested, that the Government have determined to introduce it more generally into the Navy, particularly for guard-ships; these vessels are to be of two classes, line-of-battle ships and frigates; the former having combined engines of 550 H.P. the latter 350 H.P.; the cylinders of the engines will, in some cases, be applied horizontally, and the pistons will act directly upon the propeller shafts, by cranks, without the intervention of wheels; the propeller shaft will make from 50 to 60 revolutions per minute, and the speed of the vessels will be from 5 to 7 miles an hour; this velocity will be sufficient to enable them to command their own position; and with heavy guns and the free uninterrupted use of their batteries, they will be fully equal to cope with any vessels of their class. The 'Amphion' frigate is also being fitted with a screw propeller, to move with a greater velocity than the guard-ships. She is 1290 tons, was originally built for sailing, and carries 36 guns; she is propelled by a screw of two blades, 15 feet diameter, and 21 feet pitch, driven by a pair of engines of 300 H.P., making from 45 to 50 revolutions per minute; her speed on trial was 7 knots an hour, and promised more; the whole was designed and executed by Messrs. Miller and Ravenhill. The forms of framing, the graceful proportions, and scientific combination of strength with lightness; the arrangement of the several working parts of the engines, so as to diminish the weight, and increase their compactness, without impairing their efficiency, have produced the natural consequences, not only in the fast river boats on the Thames, the Rhine, Danube, and other rivers where peculiarities of construction were specially demanded, but also in the sea-going vessels, for the mercantile as well as for the Royal Navy and the post-office service of both France and England.

Much discussion has already taken place, and is still going on, as to the best form and dimensions of propellers; nothing, however, but careful and well-conducted experiments can determine this important point. In these investigations Rennie has taken a leading part; Smith, Lloyd, Sunderland, Barlow, Guppy, Brunel, Airy, Maudslay, Field, Miller, Barnes, Penn, and others have also done a great deal. Up to the present time the double-bladed propeller has produced as good a result as any other form. In the first application of steam power to screw, or stern-propelling, cog-wheels were usually employed to drive the pro-

peller; then straps, or bands, working upon wooden or iron cylinders; and in the 'Great Britain,' endless chains were employed; in this case, however, the chain had claws, resembling teeth, attached to it, which fitted into corresponding recesses or cavities on the drum, and to a certain degree prevented the stretching or slipping to which chains of the ordinary description are liable; adhesion wheels were also tried by Messrs. Rennie, but were not found so good as cog-wheels. Latterly the system has been much simplified, by applying the piston of the engine to act directly upon the propeller shaft, and a successful result appears probable. Whilst upon this subject, the 'Great Britain,' the largest vessel constructed in modern times, must not be omitted. She is 322 feet long, 50 feet 6 inches beam, draws 16 feet of water, and is 3444 tons burthen. She is propelled by the screw, with a pair of engines of the united force of 1000 H.P.; there are four cylinders, inclining at an angle of 60°, and parallel with the keel; the pistons act by means of cranks upon a large wheel, which turns the drum with the chain and propeller shaft; the diameter of the screw is 15 feet 9 inches. She left Bristol on her first trial on the 8th of January 1845; and on the 23rd of the same month, for London and Liverpool; for New York on the 26th of July, 1845, and reached that city on the 10th of August; left New York on the 30th of August, and reached Liverpool on the 15th of September. This vessel and her machinery may be considered as a great experiment, from which useful results may be expected. She has already made two voyages across the Atlantic; and, notwithstanding the prognostications of many as to her failure, according to the report of her able and experienced commander, Captain Hosken, has answered well as a sea-boat. Since then her engines and machinery have undergone certain modifications, and some trifling alterations have also been made in the vessel, which experience has proved to be necessary, and which, from the novelty of the construction, and the great scale upon which the experiment was tried, might have been expected, and for which every allowance should be made. These alterations have improved her materially; and it is greatly to be desired that so much labour and expenditure should be attended with complete success. This gigantic structure, which has had the advantage of Brunel's assistance, is certainly bold, original, and in the right direction; for nothing but proportionable mass, power, and correctness of form, are calculated to contend with the heavy swell and gales of the Atlantic. It is by these and other well-conducted experiments, that we may look forward with confidence, at no very distant period, to the voyage between Ameriea and Europe, much as it has

already been shortened, being still further reduced. The same may be said of the voyage between India and Europe, the importance of which cannot be too highly estimated.

The advantage of steam, as an auxiliary to sailing vessels in long voyages, the steam power being only applied in calms, or when the wind is unfavourable, is beginning to be generally felt; and numerous vessels are now being fitted out upon this principle. For this purpose, the screw-propeller, with the means of taking it out of the water and replacing it when required without stopping the vessel, appears peculiarly well-adapted; for whilst it enables the vessel to retain all her sailing qualities, as well as her capability for stowing cargo, it still gives her the advantage of steam power when necessary. The steam power, as it is not intended to be the chief agent, should be compressed into the smallest practicable space, still so as at the same time to give the greatest power: in order to effect this, tubular boilers of the most improved construction and power of evaporation; direct-acting engines, in which wrought iron is substituted for cast iron whenever it is practicable, using sufficient steam of a greater density, together with ample stowage for fuel to last for the average probable time that steam power may be required, must be used. By the judicious combination of steam with sailing, the time of long voyages may be materially reduced, and at the same time considerable saving may be effected in the transport of merchandise.

THE ELECTRICAL TELEGRAPH.

Connected with, and forming a most important adjunct to, the locomotive system of communication, may be mentioned that extraordinary and useful invention, the Electrical Telegraph.

The invention consists in directing a current of electricity through a wire or a series of wires connecting together the intended points of communication. The galvanic or electric current may be produced, either by a battery or by employing the natural electric currents of the earth. The telegraph is worked by handles, which act by means of galvanism upon needles attached to the wires at the other end of the telegraphic line, through which the galvanic current is conveyed, and deflects them to points on a dial-plate, having symbols (according to Cook and Wheatstone's system) or letters or numbers to represent the intelligence to be communicated. By this means intelligence is conveyed from one point to another along the line of wires, almost as soon as conceived, and thus,

independent of the advantage as a means of conveying intelligence from one point to another unconnected with the railway, it is of great importance in the working of the railway itself, by preventing accidents, or in the event of an accident unfortunately occurring, enabling assistance to be despatched without loss of time to remedy the evil and clear the obstruction. Several persons claim the merit of this invaluable invention; it is difficult to decide with accuracy upon the claims of priority; like most other inventions, however, it has been perfected by degrees, and each party is entitled to his due share of credit. About the year 1819, Mr. Ronalds of Hammersmith is stated to have applied electricity for the purpose of effecting telegraphic communication, and succeeded so far as to complete a current through eight miles of wire. He also employed electricity as a means of communicating motion to a series of wheels. This apparatus, however, was too imperfect to be of much use; but it is evident, that the idea once propounded and partially carried into effect, to a certain extent, establishes Mr. Ronalds' claim to the merit of the discovery. In 1830, M. Ampère pointed out the means of deflecting magnetic needles by a current of voltaic electricity, for the purposes of telegraphic communication, and the principles of this discovery have, it is said, been applied to many of the modern electrical telegraphs. The first plan employed was so very complicated, and so liable to get out of order, that it was soon abandoned; but Wheatstone and Cook so completely improved upon it as almost to make it a new invention. Their system consisted of a dial-plate with symbols, to which the deflected needles pointed, when moved by electric agency. At first it was considered that it was necessary that the wires for conducting the current of electricity should be kept entirely isolated in iron pipes; subsequently, however, this was found to be unnecessary. They are now stretched between a series of posts placed at given intervals apart, beside the railway, and a dial apparatus is placed at most of the principal stations, as well as at the termini. The first telegraphic line upon Wheatstone's plan was established, in the year 1839, upon the Great Western Railway, between London and Slough, a distance of 18 miles, and since that time it has been so much improved that it is now generally adopted. It is already complete on the South-Western Line between London and Portsmouth, and is being laid down on the North-Western and on numerous other lines.

A company, called the Electrical Telegraph Company, has been formed for carrying out the plans proposed by Wheatstone, to whom great credit is due for the perseverance and ability with which he has worked out his system. Bain also claims a right to the invention, and, in addition to the means of electrical

telegraphic communication, has invented a mode of printing by it at the same time, thus affording the means of secrecy, and preventing mistakes; for the apparatus being kept locked in a room or box, no one can have access to it but the person to whom the communication is made. Other modifications of the system have been introduced, but hitherto without being extensively employed.

Another valuable application of electricity to engineering operations consists in blasting rock and other materials above and under water. The first effective application of this principle to blasting, may be said to be due to General Pasley, who employed it for blowing up the wreck of the 'Royal George,' sunk at Spithead in the year 1782, and which, by its own bulk as well as the alluvial deposit accumulated round it, formed a serious obstruction in that important roadstead. Pasley, at the request of the Admiralty, undertook to remove it, and commenced his operations on the 29th of August 1839, by sending down divers, in order to ascertain the exact state and position of the wreck; having done this, he proceeded to place powerful charges of gunpowder in water-tight tin cases in those parts of the vessel where they would have most effect, and they were exploded by an electrical current conveyed through them, by means of wires attached to them, and connected with a voltaic battery placed in a boat floating near: the explosions were instantaneous and almost unfailing, and a great effect was produced: in this manner he succeeded perfectly in removing the wreck in about two summers. The same system was afterwards pursued in removing the wreck of a vessel in the Thames, and is now generally adopted in similar circumstances. It was applied by Cubitt, at Round Down Cliff, for the purpose of removing a large mass of the cliff on the line of the South-Eastern Railway, between Dover and Folkestone: the portion operated upon was several hundred feet long, and between 200 and 300 feet high; the charge of powder consisted of 18,000 lbs., disposed in several cells in the line of the intended explosion, and properly tamped with sand: the explosion took place on the 28th of January 1843, and was perfectly successful, removing about 250,000 cubic yards of chalk rock; its success was of great importance to the railway operations, inasmuch as it materially expedited them, and considerably reduced the cost of this difficult portion of the line. This method of blasting upon a great scale is now generally adopted, and enlarges the sphere of operation in this department of civil engineering, as well as in the removal of rocks under water; for which it was used by Rennie many years since. A very successful application of gunpowder, for facilitating engineering operations, has recently occurred in the removal of a number of marl rock shoals in the bed of the

river Severn, executed by Edwards, for Grissell and Peto, under W. Cubitt. Martin Roberts also lays claim to the invention; he exhibited his experiments at the Craig Leith Quarries, in March 1839.

Thompson has proposed to effect the blasting, or rather the ignition of the powder, by means of common electricity, produced by an apparatus enclosed in an air-tight box, so as to prevent the admission of moisture; this apparatus is said to be more simple and less expensive than the galvanic battery.

CLOCKS.

Connected with the correct working of the railway system, nothing is more important than accurate time-keepers; for upon these depend the regular starting and arrival of the trains, so that one train may not interfere with the other, and collisions be prevented.

The introduction of clocks into Great Britain took place about the year 1288, and in 1326 Wallingford is said to have constructed a clock regulated by a balance, which was put in motion by weights, but whose action was extremely irregular. The great improvement of the pendulum does not appear to have taken place until about the middle of the 17th century, and the name of the person who first employed it for this purpose is not accurately ascertained. About 1641 Richard Harris is said to have constructed a pendulum clock for St. Paul's church, Covent Garden; however, as Huygens, in 1658, was the first who explained accurately the motion of the pendulum, the chief merit of its application to clocks may be attributed to him. The application of the spiral spring to the balance is due to Hooke in 1658; and the introduction of the compensating mercurial pendulum by Graham, in 1715, was the next great step in improvement; by means of this valuable invention, the unequal expansion and contraction of the pendulum from change of temperature, which rendered impracticable the accurate measurement of time, was obviated. Graham also suggested the idea of employing different metals, having different properties of expansion, so that the one should neutralize the other; his idea was afterwards carried out by Harrison, in the construction of the gridiron pendulum. For the going fusee, the compensation curb, and other improvements, he received a parliamentary reward.

The scapement, which communicates the sustaining force to the pendulum or balance, demands the greatest skill and accuracy, and various forms have been attempted; amongst others may be mentioned the original scapement-wheel,

with its teeth at right angles to the plane of the wheel; the anchor scapement, invented by Clement in 1680, which was improved by Graham, so as to render it more isochronous; the duplex scapement, which does not require such extreme accuracy in the teeth, whilst at the same time it performs equally well; the detached scapement, by means of which the teeth of the scape-wheel always rest on a detent, except when it is unlocked to impel the pallets, and is employed in chronometers where great accuracy is required; these, and many other improvements too numerous to mention, are worthy of notice.

The art of clock or watchmaking, termed horology, may be said to be principally composed of four parts:—1. The moving power, which is generally a weight for clocks or fixed timekeepers, and a spring for watches or moveable timekeepers; in the former case, the line suspending the weight should be equal throughout its calibre, and the cylinder on which it is coiled should be true; in the latter case, the form of the spring should be such that its force may act as equable as possible. 2. The scapement, which communicates the sustaining force to the pendulum or balance: the construction of this demands great skill; there are various kinds,—the common crown wheel, the anchor, the duplex, the detached, &c. 3. The means of communicating the power to the minute, seconds, and hour hands, which is effected by a series of wheels nicely proportioned and adjusted to each other, having many of the axes or centres working upon diamonds or rubies, to reduce the friction and diminish the application of oil, which is objectionable on account of its being acted upon by the temperature. 4. The regulator, which is effected by a pendulum in clocks and by a balance in watches. The striking (being merely a secondary part) is easily effected when the other great points have been determined. The perfection of the art consists in the proper proportions, adjustment and adaptation of the various parts to each other, and the combination of the several improvements above-described; this has now been so completely attained, that time can be marked so as not to vary the fraction of a second in a day. For these important and valuable improvements in this useful, and indeed indispensable art, in England, we are indebted to Wallingford, Huygens, Harrison, Graham, Hooke, Cumming, Mudge, Ellicott, Sutherland, Earnshaw, Arnold, Vulliamy, Dent, Frodsham, Parkinson, French, Kater, and others.

MINERALOGY AND GEOLOGY.

Mineralogy, geology and mining may be said to form an important branch in the profession of a civil engineer. Without some knowledge of these, the

engineer will, in many cases, find himself unable to carry on his operations with that degree of certainty and economy which is necessary to ensure success; and, independently of their value in this respect, there are few departments of knowledge which have contributed more to the advancement, comfort, and civilization of mankind: whilst, on the other hand, no class has contributed more to the advancement of them than the civil engineer, so that each department is essentially allied to and dependent upon the other. Geology enables the engineer to obtain a proper knowledge of the various strata through which he has to carry his operations; if for a cutting or embankment of a railway, it is essential to know the slopes at which the earth or rock will stand, the value and applicability of the materials excavated for his bridges, culverts and viaducts, and their capacity for water, &c., in order to form a correct estimate for working through them, whether for his cuttings or his tunnels. If for a canal, the same will apply, with the addition of the knowledge of the sources from whence his supply of water can be obtained; this latter will also apply to waterworks, in which the knowledge of the various qualities of water applicable to the economy of mankind is so essential. In the construction and maintenance of harbours, it is most important to have a thorough knowledge of the geological strata, and of the nature of the coasts where the harbour is to be situated, in order to render it easily accessible to vessels, whether for commerce or refuge, for its construction in the most economical manner, or for its maintenance, in order that the alluvial matter held in mechanical suspension by the adjacent waters shall not fill it up when made. In the management and improvement of rivers for drainage and navigation, in order that they may carry off the superfluous waters from the low lands and marshes, and at the same time maintain the channels in the most efficient state for navigation; in the formation of embankments against the ocean, in order that Nature herself may be rendered subservient, as far as is practicable, in affording the requisite protection; in these, as in the operations of smelting the minerals of the precious or the more useful metals, geology and mineralogy are of essential service to the engineer, and deserve his peculiar attention.

Mining appears to have been known and practised in Great Britain from the earliest periods of our history, for the Carthaginians are said to have conveyed tin to Tyre from Cornwall; but in those early days the operations must have been rude, and merely confined to the surface. This invaluable art made little progress until the knowledge of chemistry, and the invention of machinery, enabled mankind to extract from the bowels of the earth Nature's rich treasures,

to investigate their different properties, and to apply them to the purposes of life; the steam-engine, which enabled the miner to extract the water and enlarge the field of his operations, has been of invaluable service when the ore was raised from the mine, as also aiding in its reduction and the extraction of the metal in its most refined state. Some of the Cornish mines have been extended to a depth of more than 220 fathoms below the surface. As regards coal-mines, they also have been worked to an extraordinary extent, as in the case of the Cumberland coal-fields, which have been wrought above a mile beneath the sea. The total quantity brought to the surface and consumed annually amounts to between 30,000,000 and 40,000,000 of tons. The production of iron also has immensely increased to 1,500,000 tons. Without the steam-engine these operations would be entirely paralysed, and must cease. The total annual value of the British mineral produce is said to amount to about £26,000,000. In this valuable department we are much indebted to the establishment of the Museum of Economic Geology, which will be the means of extending the knowledge and use of minerals, as well as the best mode of obtaining them. Neither must we forget the valuable services of Sir H. De la Beche, Murchison, Sedgwick, Greenough, Buckland, Horner, Lyell, John Taylor, Griffiths, Buddle, Sopwith, Philips, Wood, Atkinson, Bald, and others, who have contributed so largely to the advancement of this important branch of science.

VENTILATION.

Connected with mining may be mentioned the important subject of ventilation, the value of which is now so universally appreciated, not only for mines, but for public and dwelling-houses. The art consists in conveying volumes of fresh air through apartments, so that the air shall be always as nearly as practicable in the proper state for respiration; but in effecting this, it is desirable that the temperature shall not be reduced too low, otherwise inconvenience may be produced in other respects; whilst ventilation, therefore, is of great importance, the artificial warming of apartments is of equal consequence, and to combine both effectually is the great desideratum. Heat is the great medium for producing circulation, as in the example of collieries and mines, and on extraordinary occasions mechanical power may be applied. The common fire-place is the most wasteful of fuel, but possesses many advantages; and, although the stove may produce a more equable temperature, a proper combination of both seems

best adapted to unite the advantage of a thorough circulation of air with the required degree of temperature; warm water and steam conveyed through pipes have been employed in many cases; those systems are however amongst the best whereby a large body of air is raised to about 100° by passing between cases filled with hot water, and is enabled to flow freely into the apartments, expelling at the same time a corresponding bulk of vitiated air; thus rendering ventilation an integral portion of the system of warming; by such a plan, warm water may also be supplied to any part of the building for domestic purposes. When stoves are used, they should be upon the principle of slow combustion, and be so contrived as to avoid producing any disagreeable odour; for this reason porcelain is much employed, and it is essential to have a thorough circulation of pure air where stoves are employed. Upon this important subject, much information has been elicited by the late Parliamentary Reports, and by the labours of Sylvester, Tredgold, Arnott, Reid, Hood, Price, C. Manby, Perkins, Haden, Stephenson, and others.

ARCHITECTURE.

The pursuits of the engineer are intimately connected with architecture, not merely as regards construction, but in taste also; and although it is not necessary that he should be so thoroughly conversant with all the details of ornament as to be able to practise as an architect, still he should be so far acquainted with them as to be able to carry out the leading principles with effect, whenever it becomes absolutely necessary in the course of his practice. The works of the engineer, associated as they are for the most part with the great operations of Nature, should be designed and constructed so as to harmonize with them. They must strike by their general mass and proportion rather than by trifling details or minutiæ of ornament, which as a matter of taste, would be misplaced and unnecessary, and wasteful as regards expenditure; consistently, therefore, with their first grand object of fitness for their purpose, they should be simple; and in the few instances where ornament may be necessary, it should harmonize with the structure, and be sparingly used.

In architectural masonry, the ancients have left us admirable models which cannot be too much studied, and may be generally followed with great effect and advantage; but the adaptation of timber and iron to modern architecture requires a different treatment. The massive proportions and dimensions which suited well the character of stone are no longer necessary, and would be misplaced

when applied to the more solid and tenacious properties of iron; here equal strength is obtained with much smaller dimensions, which, at first sight, from their lightness and apparent weakness (until the eye becomes accustomed to them), produce a feeling of insecurity which can only be overcome by time; but this feeling soon vanishes, and the great convenience, economy and security introduced by the employment of wrought and cast-iron, has caused it to be generally adopted whenever practicable. In order, however, to ensure success, great care must be taken in the selection of proper materials for its different applications, and much depends upon the mode in which it is manufactured; the right understanding of this and of the different processes of converting the ore into the several states of cast and malleable iron and steel, all of which possess very different properties, and require different proportions and dimensions in their application, demands no ordinary skill and experience. The application of heated air for the purpose of reducing iron from the ore (commonly called the "hot blast" system, invented by Neilson in 1826), has produced a considerable revolution in the character of the metal, as well as in the economy of manufacturing it, and the comparative merits of hot and cold blast iron is still a subject of controversy, which requires to be duly considered in its application to construction. Cast-iron, from the rigidity and brittleness of its texture, is not so well adapted to resist concussion, or any sudden strain, as wrought or malleable iron, and when employed, it is necessary to make greater allowance to meet it; hence the employment of malleable iron has become more general, and has, in many cases, superseded the use of the former, as while it contributes equal strength with less weight, it gives warning previous to fracture, and enables a remedy to be applied, which cast-iron does not; for these reasons it is now almost universally employed for all purposes where it is required to resist tension and sudden irregular strains, and to combine strength and lightness; whilst cast-iron is only used to resist compression, and to counteract by its mass and rigidity any tendency to movement or alteration of form. By thus carefully studying the different properties of both materials we soon acquire a knowledge of the best mode of adapting them to their different purposes, and giving to them those architectural forms best suited to their respective qualities and the objects for which they are employed. One of the great advantages of wood consists in the first economy and the facility of converting it to the several purposes where it can be employed, and hence, until the properties of iron and the mode of working it became better understood, wood alone was used in conjunction with stone and brick, both for engineering and architectural purposes; and notwith-

standing it has been altogether superseded for many purposes by iron, nevertheless it still possesses advantages in the construction of bridges, roofs and other works where the first outlay of iron or stone would be too great. Enough, I trust, has been said to show the intimate connection of the professions of the civil engineer and architect, and, without the one usurping the province of the other, it is much to be desired that a harmonious understanding should be cultivated between them, as it must tend to their mutual advantage, and nothing can contribute to this desirable object more than the meetings of this Institution, to which it is gratifying to find so many architects have attached themselves.

AGRICULTURE.

Neither must we forget the comparatively recent adaptation of engineering knowledge to the advancement of agriculture, and the various implements connected with it, for ploughing, drilling, threshing, grinding, &c. Since the improvement in the working of iron, the machines for conducting these various operations are constructed with a degree of portability, economy and efficiency which render them of the greatest importance to the farmer, and enable him to cultivate the soil, as well as to convert its various products to domestic purposes, in a much more economical and expeditious manner than formerly, and to derive a greater profit from his exertions. In the construction of agricultural implements, Messrs. Ransome, May, Cottam, Stratton and others, have greatly distinguished themselves.

In modern agriculture, under-draining forms an important and valuable principle; stagnant water generally has been proved to be injurious to agriculture, and it is, I believe, now universally admitted that without thorough drainage it is impossible to cultivate the soil effectually; for this purpose small drains formed by tiles laid from 1 foot to 4 feet below the surface, are generally adopted; the tiles are made by machinery invented by the Marquis of Tweedale, Ainslie and others at a trifling cost; the surface water is thus conveyed from the land into the adjacent main drains and thence to the rivers. Water is the grand natural fertilising agent, and any amount of care in its proper distribution is well bestowed: it is therefore worthy of consideration, whether in hilly countries and districts subject to alternations of dry and wet seasons, it would not be advisable to establish large reservoirs for water, to be used during dry seasons for irrigation, in the manner adopted by the ancients; by this means districts might be cultivated with advantage, which now are comparatively sterile. Artificial irrigation is now

much practised, and the extensive water meadows of the Duke of Portland near Welbeck are well worthy of notice. In this essential department, Smith of Deanston, Parkes and others, have made considerable progress, and the scientific researches of Davy, Brande, Buckland, Liebig, Johnston, Gardiner, Philips and others, under the patronage of the Royal Agricultural Society, which includes the names of the most distinguished nobility and gentry in the country, have contributed materially to the advancement of agriculture; and since the public attention has become alive to its importance, and means suitable to the end have been devoted to its improvement, there can be little doubt but that its future progress will be in a ratio commensurate with it.

SURVEYING.

Land and maritime surveying form an essential department in the profession of a civil engineer; without a correct knowledge of the former, it is impossible for him to lay out and determine in the best manner the proper lines of communication in a district, whether by canal, railway, or common road; and without a knowledge of the latter, it is equally difficult for him to decide upon the best situation for a port, and the most advisable means of improving and maintaining it. In these valuable departments much progress has been made. The great Trigonometrical Survey of the British Islands, which is now very nearly completed, is the greatest work of this kind ever undertaken in this country, and serves as a model for minor works of this nature. It was commenced by General Roy in the year 1783, under the direction of the Ordnance Department of the Government, and has been subsequently carried on, with equal ability, by General Mudge and Colonel Colby, of the Royal Engineers, under whose direction it now is. This great work, so far as it has proceeded, has already proved of essential service to the civil engineer, inasmuch as all the towns and villages, the chains of hills, valleys and rivers being laid down trigonometrically, his labours, as well as the expenses of his employers, are materially diminished, in tracing out the best lines for railways or other internal communications; instead of having to survey the whole district of his operations trigonometrically, he has only to take the leading points, and to fill in the detail of fields, buildings, &c. to a larger scale; and even before incurring this labour he can, with one of the Ordnance maps in his hand, determine in a great measure the general direction and course of his line; notwithstanding this, it is essential for him to have a thorough knowledge of the use of instruments, the theodolite, sextant,

and transit, the most accurate mode of measuring bases, and to see that those employed under him are competent to their task, and employ the necessary means to ensure accuracy in their surveys. Connected with surveying, we must not omit the important department of leveling, for simple as it is, nothing requires greater accuracy, in fact, upon this being properly done the success of the whole scheme or undertaking in hand may be said mainly to depend; too much attention, therefore, cannot be paid to it; the instruments employed should be of the best construction, simple and substantial, easily adjusted, and kept in good order; the levels should be referred to one datum and proved in various ways, and recorded in a plain intelligible manner, so that they may at all times be easily referred to.

Maritime surveying requires an intimate knowledge of the general laws which govern the tides, the set of the currents, the prevalence and direction of the winds, the soundings, anchorage ground, &c.; these should be regularly observed for a given period, in order to ascertain every possible variation, and regularly registered and referred to the same datum. For this purpose, self-acting tide-gauges, with a clock apparatus attached to them, for marking the time of high and low water, if placed in proper situations, are extremely valuable: that at Sheerness Dockyard, by Mitchell, and the improved one at Ramsgate Harbour, are worthy of remark.

Mineral or underground surveying differs only from the above in its being necessary to ascertain the dip or angle at which the several strata lay, their general direction and thickness, their quality and value, and the best mode of working them. For laying down the underground survey, the magnet and circumferenter are much employed.

In the investigation of the laws which govern the tides, we are much indebted to the valuable scientific researches of our honorary members Lubbock, Whewell, Airy and others. Connected with the various branches of surveying, the construction of philosophical instruments is entitled to an important station; as without accurate instruments it is impossible to make correct surveys, and for the construction of these we are much indebted to the labours of Ramsden, Troughton, Dollond, Carey, Simms, Watkins, Jones, Elliott, and others.

DRAWING.

Drawing and modeling, although minor, form valuable, and, in fact, indispensable departments in civil engineering; for unless the various projects pro-

posed to be carried into effect are in the first instance correctly delineated upon paper, it is impossible to convey a just idea of them, or to form a correct estimate of the cost. Drawing may be classed under three heads:—mechanical or geometrical drawing is that whereby the plans and sections are simply represented as they would appear on a plane surface; perspective drawing consists in representing the objects as they appear when seen from a given distance and height; this kind of drawing, although very useful, and indeed indispensable to the architect, in order to represent the true effects of light and shade of his different compositions, as they would appear when carried into effect, and upon a true perception of which the success of his building will mainly depend, is not of that importance to the engineer, whose works are of a different kind, and much more extensive, so that to represent them perspectively would, in many cases, be impracticable; but inasmuch as in detached portions of his works, such as important bridges, viaducts, machinery, &c., perspective drawing may be employed with great advantage, it ought to be studied. Landscape and topographical drawing is also useful, in order to convey to unscientific persons an idea of a particular locality, in the manner they are accustomed to view it, where works are proposed to be executed, and thus to remove fancied objections which otherwise might be overcome with difficulty; and this is still more successful with the application of colours when applied as seen in nature. These different kinds of drawing should be carefully studied and practised with accuracy, as they will be found essentially to forward the views of the engineer, and give satisfaction to his employers.

Although drawing, however, is most valuable, modeling in many cases is essential; for in the former case the objects are merely represented upon paper, assisted by light and shade and perspective, which to persons in some measure acquainted with the subject conveys a tolerably correct idea of what is proposed to be done, but a model represents it (although upon a reduced scale) exactly as it is intended to be, with the different planes, dimensions, and surfaces; hence nothing, except the work itself, gives such a perfect idea or representation as a model; it also enables the engineer to detect many imperfections which otherwise would escape his notice; whenever, therefore, models can be conveniently adopted or employed, it is advisable to do so; and it is gratifying to know that the art of modeling has made considerable progress, so that now they can be obtained at a moderate cost in wood, card-board, plaster and clay, and will thus be more generally employed. In this department, Salter, Deighton, Day and others, have attained deserved celebrity. Working models of machines are extremely

useful to give an idea of the action of a machine, but we should be cautious in drawing conclusions from the results, for it too frequently happens that a machine succeeds extremely well when tried in a model, but fails when put in practice; we should, therefore, merely consider the results of working models as guides to be worked out practically, and in this way they are extremely useful.

METEOROLOGY.

The principles of this science, as far as they have yet been determined, claim our particular attention. Without a knowledge of the winds, and the quantity of rain falling in a particular district, we cannot determine with precision the proper form and dimensions of moles or piers to resist the action of the sea, or of drains to carry off water from extensive districts of marsh land, or of the extent to which it may be necessary to improve the channels of rivers; or in carrying lines of railway through a country, to design the works in such a manner that they may withstand the shocks of the elements; neither can we select the proper kind of stone or other materials for constructing buildings, unless we know the vicissitudes of climate to which they may be exposed, or the extent to which they may be acted upon by it. In the investigation of the phenomena of this difficult science, we are much indebted to the late Professor Daniell, and to C. H. Smith, whose report upon the qualities of the different kinds of stone, as regards their tenacity, hardness, capability of resisting moisture, and durability, for the purpose of selecting the best material for the New Houses of Parliament, forms an important and useful example, for which the engineer and the architect are much indebted; and the same course should be followed, as far as is practicable, previous to commencing every great work, and indeed for the want of it we find now many magnificent buildings partially decayed which otherwise would have been in good preservation.

PATENTS.

The improvements in manufactures, machinery, and other branches of art, resulting from a great number of curious and valuable inventions, necessarily gave rise, on the part of the successful inventors, to a desire to secure for themselves and their posterity, as far as is practicable, the benefits of their labours. The Government, perceiving and duly appreciating the advantages which not only the inventors themselves, but the nation at large, derived from them, wisely

resolved to give every possible encouragement, by securing to them the exclusive right and title to their inventions for a certain number of years, and to enable them to recover by legal process, severe penalties against any person attempting to use their inventions, without the previous consent of the inventors themselves. Hence arose the Law of Patents, or a privilege of the Crown to grant Letters Patent, conveying to the persons mentioned therein, the sole right to use or dispose of some new invention or discovery for a limited period, which is generally about fourteen years. It is difficult to fix the date of the first assertion of this privilege of the Crown, but it was first defined by statute in the reign of James I. The law has at various times undergone certain alterations and modifications, so that it now forms a branch of itself, which, with its various complicated relations, demands a peculiar study. Ever since the reign of Anne, parties have been compelled to specify in detail the particulars and nature of their invention or discovery, previous to being able to obtain Royal Letters Patent. The great number of inventions, which have multiplied considerably of late years, has given rise to an important class of professional gentlemen styled Patent Agents, who devote themselves exclusively to the study of inventions and the peculiar laws relating to them, in order to secure to inventors their just rights and prevent them from being infringed upon by others. Amongst these gentlemen we may mention the names of Farey, Carpmael, Robertson, Newton and others, to whom inventors are much indebted for the skill and attention with which their interests are guarded; as also to Rotch, Webster and others, who have devoted themselves to the study of the Patent Laws, and have written ably upon them.

THEORY AND PRACTICE.

In the preceding pages, my remarks have been almost exclusively confined to the notice of the various works which have been carried into effect by civil engineers since the time of Smeaton; and although practice, upon the whole, is most important, nevertheless we should not omit the study of the theory, or principles upon which that practice is, or ought to be, founded, and without the due study and comprehension of which, we may frequently be led into great errors in practice. Our junior members should, therefore, previous to commencing their professional career, be well versed in arithmetic, algebra, mathematics, mechanics, and the principles of natural philosophy in general, and the mode of applying them to practice. They should cultivate a patient and equable temper of mind, in order to enable them to investigate, with rigid impartiality, the principles so beautifully

illustrated in nature, and upon which the great operations which may hereafter be entrusted to their charge as civil engineers depend ; and once having found out, and thoroughly understood these principles in all their various applications, they should never depart from them, always bearing in mind, that nature will submit to assistance and guidance for the benefit of mankind, but never to opposition with impunity ; her laws are immutable, and we may be assured that, either for good or evil, the same causes will produce the same effects ; if, therefore, we wish to command success, we must adhere to her laws, and when once we thoroughly understand them, we shall be amply rewarded for all our toil ; difficulties will vanish, and success will invariably attend our efforts. Previous to commencing practice, our junior members should not neglect the workshop ; on the contrary, it would contribute materially to their advancement to undergo an apprenticeship of some years in that department ; for inasmuch as the success of many of the works in which they may hereafter be engaged, particularly the mechanical, depend in a great measure upon the correct application of the principles which can be only thoroughly learned in the workshop, that is the place in which they must be studied ; moreover, it will imprint indelibly in their minds the principles which they acquire from books, and induce a degree of accuracy of thought and execution which cannot be acquired elsewhere ; hence we find that some of our greatest engineers, both of the past and present age, have there acquired a considerable portion of their education, and owe a great degree of their celebrity to that invaluable nursery for engineers. Nothing, therefore, can be more erroneous than to suppose that theory and practice are incompatible with each other, for they are intimately connected with and dependent upon each other. Without a thorough understanding of the theory or principles upon which engineering is founded, it is impossible to carry them into practice without endless failures and wasteful expenditure of means ; and without the experience derived from practice, the principles acquired from theory will be of little avail ; both therefore must be carefully studied and combined in order to produce a good engineer. Finally, composition, or the art of putting ideas into simple, clear, and intelligible words, should be studied, in order to convey to the world just notions of the measures proposed ; also an intimate knowledge of the value of materials and workmanship, in order that he may be enabled to make correct estimates, upon which the success of all commercial undertakings so materially depend.

CONTINENTAL ENGINEERS.

In making the above remarks, I have endeavoured to confine myself strictly to what has been done by civil engineers in England during the past and present centuries; but in so doing I should be extremely sorry to be considered as detracting from, or underrating in the least degree, the great merits of continental engineers, or the progress which has been made by them also during the same period, and we are proud to number many of them among the members of this Institution. To attempt to enter upon this equally interesting as instructive subject, would compel me to trespass much longer upon your patience, which I fear has been already tried too much; but I cannot omit remarking, that the greatest credit is due to our professional neighbours on the Continent, for the example which they set in the infancy of the science, when it was so little known in this country, and for the great progress which has subsequently been made, and the numerous inventions which have emanated from them. In Italy, we have only to mention the harbours of Genoa, Venice, Ancona, Civita Vecchia, Leghorn and Naples; the canals and silk machinery of Lombardy; the bridges over the Po, Tisino, Adige, &c.; and the names of Leonardo da Vinci (said to be the inventor of the pound-lock), Gugielmini, Frisi, Manfredi, Martinetti, Fazio, Miliani, and numerous others. In France, the mole and docks of Cherbourg, Toulon, Brest, Havre, Boulogne, Calais and Dunkirk; the canals of Languedoc, Burgundy and Picardy; the embankments of the Loire; the bridges of Neuilly, Bordeaux, the Dordogne; and the names of Belidor, Papin, Gauthey, Rondelet, Dupin, Perronet, Prony, De Cessart, Lamblardè, Reibel, Sganzin, Frissard, Hallette, Navier, Jacquard, Vicat, Neveu, Cordier, and Teisserene and others. In Switzerland, the Alpine roads of the Stelvio, Mont Cenis, St. Gothard, the Splugen, the Brenner, the Simplon, &c. In Holland, the magnificent embankments for defending the country from the sea; the great Texel, and numerous other canals. The system of drainage, although perhaps too complex and artificial, is also meritorious and worthy of remark. Throughout Germany, the system of managing the great rivers Danube, Rhine, Elbe, the bridges across them, the canals connecting them together, as well as the roads and mining operations. In Sweden, the docks of Carlscrona and the Trohlhatta canal; and in Russia, the docks at Cronstadt and Revel, the extensive inland navigation, roads, &c. In Spain, the moles of Malaga, Alicant, Tarragona and Barcelona; the docks at Ferrol, Carthagena and Cadiz, and the Arragon canal; and the railway system, which owes its origin to this country, is now making

rapid progress everywhere on the Continent. Neither must we omit to notice the ingenuity and vigour of our transatlantic brethren in the United States, to whom the world is much indebted for their many splendid public works and useful mechanical inventions and discoveries.

I have thus endeavoured to take a rapid survey of the different departments which constitute the profession of a civil engineer since the commencement of the last century, or, rather, from the time of Smeaton down to the present day. Imperfect, however, as this survey has been, I fear it has trespassed too much upon your valuable time, although the interest and importance of the subject justly entitle it to far greater notice, and would amply repay the perusal, if it had been treated by an abler hand, at even much greater length. Looking back to the humble goal from which we started, a little more than a century since, and then adverting to the exalted pinnacle upon which we now stand, what almost immeasurable space have we traversed—what triumphant progress have we made! In how great a degree have both public and private prosperity, and the civilization of mankind been promoted by it! Within a few years our profession was comparatively unknown, and the great and beneficial results which have sprung from it were never anticipated; now it is universally in the ascendant, and it may be said so with reason; for without presuming to undervalue the merit sand importance of other professions, that of the civil engineer may be said to embrace everything which can tend to the promotion of the comfort, the happiness, and the civilization of mankind, and to be founded upon principles of the highest order.

Comparatively speaking, only a few years have elapsed since Great Britain, as regards engineering works, was in a very backward state: she had neither roads, canals, harbours, machinery, nor manufactures worthy of being compared with those of her neighbours on the Continent. Let the comparison be made now, and we find that if we do not surpass every other nation, we are inferior to none. And to what may this extraordinary change be attributed, but to the progress of civil engineering? Notwithstanding, however, we have advanced thus far, much still remains to be done. Great as has been the result, we may be said scarcely to have passed the threshold of improvement. It is true we feel the influence of our position, but this can only be maintained by further advancement. To stand still is to retrograde; our career must be onward; and what has been done should only serve as a stimulus to greater exertions. We have still a very wide field before us; let us, therefore, by our united exertions, cultivate it to the very utmost; let us never rest satisfied so long as anything remains to be done.

Much yet remains to be discovered in the formation, construction, and maintenance of harbours, in order to afford the greatest facility of ingress and egress under all circumstances, without at the same time diminishing the necessary protection and depth;—in the improvement of rivers, so as to enable them to drain and carry off the floods effectually from the adjacent marsh-lands and valleys, and at the same time to render them capable of navigation to their utmost extent; to point out the most effectual means of enabling them to discharge their fresh waters into the sea or estuaries, and to receive the tidal waters without causing them to deposit the alluvial matter held in suspension by their waters, in such a manner as to form injurious bars or shoals;—in determining the best form and construction of vessels, so as to render them capable of giving the least resistance in their passage through the water, and conveying the greatest burthen or cargo with the utmost safety and velocity;—in determining the best form, dimensions, and construction for locomotive-engines for any gauge, so as to combine the utmost capability of producing steam with the least quantity of fuel, and drawing the maximum load with the greatest velocity combined with the greatest safety and economy;—in determining the proper width of gauge which shall satisfy all the required conditions of safety, economy, and speed;—in determining the most expeditious, safe, and economical means of transferring goods, passengers and carriages from one line to another, whenever a break of gauge becomes necessary;—in determining the best and most economical mode of constructing and laying down the permanent way, in such a manner as to enable the trains to travel with safety at the greatest speed the engines are capable of producing, with the least wear and tear either to the permanent way or to the engine and carriages;—in determining the resistance of railway trains;—in devising means for obviating the leakage by the valve in the atmospheric system;—in discovering a substance for sealing the valve which shall preserve the desired consistency under all degrees of temperature; and in generally investigating that system of traction, in order to remedy any practical defects which may exist, and to ascertain when it may be applied with the greatest advantage;—in the improvement and adaptation of machinery to many new objects in the arts and manufactures, and in the application of chemistry and geology to our operations. These, and a variety of other improvements, are to be desired, and worthy of our particular attention and study. The steam-engine itself, improved as it is, and wonderful as have been the results produced by it, is capable of further improvements. Its bulk and weight may be further diminished, both in the form and construction of the boiler as well as in the engine itself, and thus,

in effect, its power may be increased; or it may be reserved to us to discover the means of producing and rendering subservient to our purpose some other power which shall surpass steam, or perhaps to substitute for it that all-powerful agent electricity, which Jacobi has already attempted to apply to navigation. Obscure and difficult as the subject may appear now, it may still be realized. Our indefatigable and enlightened honorary member, Faraday, has pointed out the way, and is still proceeding in his distinguished career with remarkable success, and we must not lose the opportunity of profiting by it: in fact, by well-directed and combined exertions, it is impossible to foresee the results which may yet be arrived at.

This Institution, which but a few years ago was scarcely known, has now taken its station amongst the first scientific societies of the kingdom; and as its objects are second to none in importance, whether as regards their public or private utility, so must it continue to flourish and increase in importance if those objects be only legitimately and steadily prosecuted. In order to effect this, we must not relax in our exertions—there must be no schism among ourselves; the Institution must be our rallying-point; we must all work for the common good. We must contribute to its advancement, as well as that of our profession, by every means in our power—whether by papers, by verbal discussions, by contributions to the model-room or the library, or by the construction of works which shall serve as examples worthy of being followed—in fact, in every practicable manner, each according to our several opportunities.

Let the senior members, both by their precept and example, and their forbearance, courtesy, and assistance towards each other, with liberal and right-minded zeal for the honour of themselves and their profession, point out to the junior members the true road to eminence; and as they, by the common lot of mortality, must quit this transitory scene, let them be succeeded by others fully competent to fill their places, and to enlarge the boundaries of their profession.

On the other hand, let the junior members look up to their seniors as friends, and as sure guides to follow, and from whom they may with confidence seek for assistance in the hour of need; and, banishing all jealousies or other ignoble feelings, let them rally round and support their seniors under all circumstances. Let the chair of this Institution be an object of honourable ambition to the youngest Graduate, as a goal to which he may look forward as one of the rewards, and that not the least, of his successful exertions in his professional career.

By thus pursuing steadily, and with one vigorous and united effort, this grand